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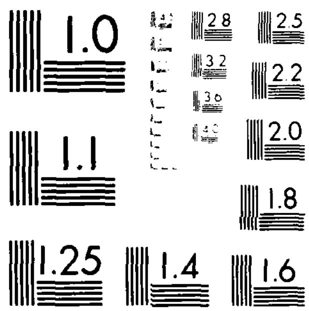

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AN ASSESSMENT OF THE IMPACT OF WRSK EOQ
ITEMS ON AIRCRAFT READINESS
USING DYNA-METRIC

Michael J. Budde, Captain, USAF
David B. Graham, First Lieutenant, USAF

LSSR 96-83

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This research developed a methodology to expand current War Reserve Spares Kit (WRSK) capability assessment techniques to measure the impact that EOQ items have on aircraft readiness using Rand's Dyna-METRIC Recoverable Inventory model. An F-16 WRSK was analyzed using a tactical wartime scenario to evaluate current WRSK stockage policies for EOQ items. The results of this study revealed that the authorized stock levels for some EOQ items were inadequate, thereby significantly reducing the overall readiness support reportedly provided by the WRSK. The methodology developed for this research is applicable to all WRSK capability assessment evaluations.

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AN ASSESSMENT OF THE IMPACT OF WRSK EOQ ITEMS ON AIRCRAFT READINESS USING DYNA-METRIC

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Michael J. Budde, BA
Captain, USAF

David B. Graham, BA
First Lieutenant, USAF

September 1983

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This thesis, written by

Captain Michael J. Budde

and

First Lieutenant David B. Graham

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CHAPTER I

INTRODUCTION

Purpose

The purpose of this research is to assess the impact that selected EOQ items in War Readiness Spares Kits (WRSKs) have on aircraft readiness. Currently, no methodology exists which can realistically measure the support provided by EOQ items in a WRSK. Therefore, critical evaluation and assessment of this aspect of WRSK authorization/stockage policy is not possible. This research introduces a means of assessing the overall aircraft readiness attainable with a given WRSK, including the impact of EOQ items, which has not been considered in WRSK capability assessment to date. With this proposed technique, the Air Force will be able to evaluate the adequacy of its WRSK computational methods for EOQ items, and ensure that existing WRSKs should perform as expected. The enhanced assessment capability proposed in this research directly supports one of the current goals of the Air Force supply system identified in the White Paper (13:6).

Background

Never before in history have the challenges of meeting our national defense objectives been so great. To

be effective in this mission, Air Force managers must efficiently manage scarce resources through scientific planning, assessment, and execution of sound logistical strategy. It is very difficult to forecast whether a military unit has adequate logistics support resources and processes to meet its future wartime needs. Logistics planning represents a major link in the accomplishment of force projection; therefore, greater emphasis must be placed on assessing and identifying logistics support capability in order to realistically appraise the level of readiness provided by a given amount of assets. The Air Force is making positive efforts to better understand the dynamic relationship that exists between logistics resources and mission effectiveness.

The objective of the Air Force logistics system is to "contribute to operational effectiveness by providing the material resources necessary to establish, sustain and modernize the U.S. Air Force [27:1]." To be effective, the logistics system must go one step further and ensure the required resources are in the right place at the right time (1:p.3-1). The successful accomplishment of the Air Force mission is dependent upon receiving this effective logistics support, which includes adequate repair facilities, trained maintenance personnel, supply capacity, spare parts and consumable materials. As AFM 1-1 points out: "because this support determines the limits of our

operational capability, it must be kept at the peak of readiness [24:p.4-13]."

The fighting capability of the Air Force depends upon the operability of its weapon system components. The physical hardware making up these components has a natural tendency to deteriorate and malfunction with age and heavy usage. Therefore, one cost-effective way to ensure the availability of these weapon systems is to maintain a sufficient inventory of mission-essential spare parts in some proportion to the frequency of their failure. Thus, a sufficiently high level of spare parts inventories is a critical function of the logistical support system.

In order to more effectively manage these inventories of essential spare parts, the Air Force uses various classification and coding systems to group parts with similar characteristics. The broadest classification groups parts into two categories: expendable items and nonexpendable items. Expendable items are those which are consumed in use or lose their identity by installation on a higher assembly (28:Vol.1, Part 4, p.1-401). Nonexpendable items are various types of repair and support equipment which retain their identity as separate entities throughout their life cycle. Both expendables and nonexpendables can be further classified as recoverable through repair or nonrecoverable, which refers to those items not normally subject to repair (28:Vol.1, Part 4, p.1-402). Economic

Order Quantity (EOQ) items are generally those classified as expendable and nonrecoverable (22:p.1-1).

Although the inventory requirements for peacetime flying programs are relatively stable and can be derived from historical data,

> . . . the transition from peace to war so drastically changes operational demands and support processes that logistics managers cannot merely extrapolate peacetime experience to ensure adequate wartime capability [15:V].

Therefore, logistics managers must focus their attention on attaining sufficient inventory levels of critical spare parts to ensure that the combat capability of engaged forces is not diminished due to lack of resources (25:4). This need for sufficient levels of spare parts is even more critical today than in the past. With current strategic stockpile shortages, production roadblocks caused by long component manufacturing lead times, and skilled labor shortages, it is highly unlikely that the industrial base could mobilize soon enough to support ongoing wartime requirements (9:15; 19:81; 24:79-85). This suggests that future conflicts will be fought with the assets on hand. Therefore, the selection of proper levels of these assets will probably have a direct impact on the outcome of a war.

Recognizing this critical logistics function, Air Force Logistics Command (AFLC) manages a War Reserve Materiel (WRM) program to ensure the necessary wartime assets are identified, obtained, and properly maintained.

WRM are those assets, in addition to peacetime operating stock, needed at the start of a conflict to support active forces until industrial production can sustain combat requirements (17:738). WRM is either prepositioned at planned operating bases or prestocked in the AFLC wholesale logistics system to support the force after the prepositioned assets are used (29:pp.1-2 to 1-3). There are three categories of WRM: (1) spares, which are parts, subassemblies, or assemblies used to maintain or repair systems, equipment, and nonaircraft items; (2) equipment, including support, communication, and civil engineering equipment and vehicles; and (3) consumables, which are expendable items directly related and necessary to a weapon system (e.g., munitions, petroleum, oil and lubricants, racks, and pylons).

WRM spares are prepositioned as WRSKs and Base Level Self-Sufficiency Spares (BLSS). WRSKs are

> . . . air transportable packages of spares and repair parts required to sustain planned wartime or contingency operations of a weapon system for a specified period of time [28:Vol.1, Part 1, p.14-31].

BLSSs are non-mobile spares packages intended to support increased wartime activity for units or activities which do not deploy from their peacetime bases, but have a wartime tasking (28:Vol.1, Part 1, p.14-31). This research deals only with expendable items, both recoverable and EOQ, contained within a specific WRSK.

The Air Force uses a marginal analysis technique in its WRSK/BLSS Requirements Computation System (D029) to determine the optimal levels of recoverable items to include in WRSKs. In order to assess the effectiveness of the stockage levels established by the D029 system, the Air Force uses the Dynamic Multi-Echelon Technique for Recoverable Item Control (Dyna-METRIC). Dyna-METRIC is a recoverable inventory model capable of estimating the probability of achieving a desired readiness rate for a given level of stock. It can also compute the stock required to achieve desired levels of aircraft readiness, although it is not currently being extensively used in this mode. To the extent real world stock levels are based on the estimates/analysis of this model, Dyna-METRIC predicts realistic wartime readiness capabilities.

Although models are representations of the real world, they may never exactly duplicate reality. Inevitably, some simplifying assumptions are necessary to make the model a workable estimate of reality. The nature of these assumptions will determine how closely the model represents the real world, and also the accuracy and reliability of the outputs of the model. Furthermore, unrealistic assumptions may result in inefficient use of resources and can mean the difference of whether or not we maintain the capability to meet our national defense objectives. Therefore, it is extremely important that the impact of

the model assumptions be thoroughly analyzed and tested. One assumption made by inventory models of recoverable items deals with cannibalization.

Cannibalization is a logistical management practice defined as:

> . . . the authorized removal of a specific assembly, subassembly, or part from one weapon system, support system, or equipment end item for installation on another end item to meet priority mission requirements with an obligation to replace the removed item [26:5].

In other words, it provides an additional source of spare parts when stock is low or service times are long. For example, consider the case of an aircraft that is not operational due to a malfunctioned component. While that aircraft is nonoperational, it provides a source of supply for other components. That is, one aircraft provides a hedge against other aircraft becoming nonoperational due to shortages of other items.

In general, the treatment of cannibalization in Air Force inventory stockage models has been both deficient and unrealistic. Only in inventory models where the objective function is to maximize aircraft availability is cannibalization an important consideration. In these models, cannibalization directly affects aircraft readiness because the readiness rate achieved depends on whether cannibalization is used to consolidate failed components into the least number of aircraft. Dyna-METRIC is one recently developed recoverable inventory model which does maximize aircraft

availability. Initial versions of Dyna-METRIC either prohibited cannibalization of any parts from one aircraft to another (no-cann mode) or cannibalized all parts in order to maximize aircraft availability (full-cann mode). This treatment of cannibalization ignores the varying feasibility of cannibalizing individual components and could lead to gross over/underestimation of wartime spares requirements, potentially incorrect WRSK composition for operational flying units, and inaccurate capability assessment of alternative logistics policies. Specifically, a full-cann assumption tends to underestimate the true stock required, while the no-cann assumption tends to overestimate the stock required (6:3). It would appear that reality lies somewhere between the two extreme treatments of cannibalization. The RAND Corporation (RAND) released version 4.2 of Dyna-METRIC in April 1983 which allows cannibalization classification of individual items. This new treatment of cannibalization should more closely estimate the true readiness provided by WRSKs.

Being a recoverable model, Dyna-METRIC has been used only to assess the readiness provided by recoverable items. However, EOQ items are also included in WRSKs. In fact, the majority of the kit used in this research was made up of EOQ items. The stock levels for these items are estimated at base level by maintenance technicians based on peacetime demand rates (20). To date, there is

no method of determining the effectiveness of the quantity levels established for these EOQ items in a WRSK.

Justification

As specified in AFR 400-24, only mission essential items are included in WRSKs. Although EOQ items are generally small, inexpensive items, they are nevertheless, essential for fully mission capable (FMC) aircraft and/or overall mission effectiveness (18). Therefore, insufficient quantities of these parts can lead to non-mission capable (NMC) aircraft and, thus, result in reduced wartime readiness. Given the potential lack of precision in estimating EOQ stock levels, it is essential that a method be developed to analyze the effectiveness of these WRSK quantities so that the true readiness support of these WRSKs can be estimated with a reasonable degree of accuracy.

Problem Statement

There is a need to determine if current stock levels of WRSK EOQ items are sufficient to meet a desired level of aircraft performance. Also, there is a need to know if the level of support provided by WRSKs is dependent upon the cannibalization treatment employed.

Research Objectives

The objective of this research was to first assess the aircraft readiness provided by the currently authorized

stock levels of EOQ items in an F-16 WRSK, thereby determining the adequacy of EOQ stock computation methodology. Given this assessment, a subobjective was to determine if cannibalization treatment, a major assumption of this model, affected the magnitude of the EOQ items' influence on aircraft readiness.

A second, but related objective was to show that Dyna-METRIC can be used to assess the readiness capability provided by EOQ items, as well as recoverable items. In order to accomplish this, however, it was first necessary to show that the required data could be obtained.

Research Questions

1. *Given an aircraft readiness rate based on recoverable items only, what is the impact of EOQ WRSK items, at current authorization levels, on that established readiness rate?*

2. *Given EOQ WRSK items do affect aircraft readiness, is the magnitude of their impact dependent upon the treatment of cannibalization selected (full-cann versus no-cann)?*

Scope

Dyna-METRIC was used to measure the level of aircraft readiness provided by a WRSK supporting a single F-16 squadron. This model was selected because of its unparalleled sophistication in modeling real world

contingencies and wartime environments, its capability to assess current and planned stockage policies, and its versatility in treating component cannibalization.

The F-16 weapon system was selected primarily due to its state-of-the-art design which permits extensive cannibalization, its requirement for a WRSK to support its tactical mission, and because it is currently receiving Dyna-METRIC analysis by Headquarters, Tactical Air Command (HQ TAC) and AFLC. Thus, the F-16 weapon system appeared to be a suitable selection for addressing the relationship between EOQ WRSK assets and aircraft readiness, as well as the treatment of cannibalization.

This research analyzed the contents of a single F-16 WRSK; the one selected by HQ TAC contained the largest quantity of EOQ parts, since EOQ items are the main concern of this research. The data necessary to make the Dyna-METRIC analysis had to be obtained from a multitude of sources. HQ TAC provided a D029 listing of recoverable item data and a selected WRM List/Requirements and Spares Support List (D040) containing the EOQ item data. The information necessary to calculate current usage rates for the EOQ items was obtained from Nellis AFB, Nevada (via HQ TAC), since it had the most comprehensive usage data available on the F-16 aircraft (18). The quantity per assembly (QPA) data for each EOQ item was extracted from

the Integrated Logistics Data File (ILDF) at Ogden Air Logistics Center (ALC), Utah.

HQ TAC provided an unclassified scenario and flying hour program that would approximate an actual wartime deployment to an appreciable degree. This included a realistic surge in flying hours early in the deployment and other scenario parameters causing the F-16 squadron to operate solely from its authorized WRSK (with no resupply for thirty days).

Although Dyna-METRIC can be used universally to assess the readiness impact of WRSK EOQ items, actual results pertain only to the weapon system and specific WRSK analyzed due to the unique makeup of each kit. However, logistics managers should find general trends useful in applications/replications using their own data base and scenario.

CHAPTER II

LITERATURE REVIEW

Overview

Basic inventory theory will be highlighted only to the extent necessary to understand the analytical process involved in current Air Force inventory stockage models. It is important to understand this process because of the mathematical dependence on the assumptions made regarding cannibalization and its probable impact on system output parameters (8:35). The various models discussed build on one another through an evolutionary process. Since Dyna-METRIC (version 4.2) appears to enjoy the highest degree of sophistication and potential usefulness in managing billions of dollars worth of Air Force assets, it will receive a more detailed examination, particularly with respect to cannibalization.

An explanation of how the term "readiness" is used in this research will be followed by a discussion of parts classification and coding methods applicable to this research. Next, a major section on WRSKs will discuss how WRSKs are developed, what they contain, and how item quantities are computed. The subject then shifts to a cursory examination of general inventory principles, followed by a discussion of the significance and meaning of inventory

performance measures. A short discussion of cannibalization will lead into an overview of inventory stockage models and their respective treatments of cannibalization. Lastly, a summary of Dyna-METRIC's capabilities, limitations, and assumptions will be provided. However, mathematical formulation/derivation will be provided only to the extent necessary to address the specific issues addressed. There have been few studies specifically addressing the impact of EOQ items on aircraft readiness. Therefore, the main thrust of this literature review is to establish an understanding of important underlying and related concepts. The reader is referred to Appendix A for a listing of acronym definitions used in this research.

Mission Capability and Readiness

The capability of a particular aircraft to carry out its mission may vary depending on the status of various equipment on board. Status codes are used to designate the degree of mission capability. Full Mission Capable (FMC) means that the aircraft has all systems working needed to perform all of its primary missions (23:12). Partial Mission Capable (PMC) means that the aircraft has systems that are working to perform at least one, but not all, of its primary missions (23:13). This status code may be followed by a reason code meaning maintenance (M), supply (S), or both (B). Not Mission Capable (NMC) means

the aircraft cannot perform any of its primary missions. It, too, can be followed by a reason code.

Although there are many ways to define readiness, for this research it is defined as the probability of having a target percentage of FMC aircraft for a given unit. This measure of readiness can also be expressed in terms of NMC aircraft; because Dyna-METRIC cannot model PMC aircraft, the probability of NMC aircraft is equal to one minus the probability of FMC aircraft.

Parts Classification and Coding

The Air Force uses various classification and coding systems to better manage its inventory and supply functions. The major parts classification of concern to this research is by Expandability, Recoverability, Repairability Category (ERRC) codes (28:Vol.1, Part 4, Atch.27, pp.1-401 to 1-405). ERRC grouping determines the type of management employed, the methodology used for computing requirements, and forms a basis for reporting usage data. A three-position ERRC designator equates to a single-position ERRC code that can be used when space is a limitation on computer listings. The first position of the ERRC designator specifies whether a part is expendable ("X" coded) or nonexpendable ("N" coded). The second position designates the recoverability of the item and the maintenance/repair level where condemnation decisions are made. A "D" identifies recoverable items that require depot level

repair and condemnation, an "F" identifies recoverable items which can be repaired and condemned at the organizational or intermediate levels, while a "B" identifies items that cannot be repaired, and are thus nonrecoverable. Although "B" items cannot be repaired, some may be subject to reconditioning. The third position, in conjunction with the first two, identifies the management system applied to the item. Table 1 summarizes the ERRC codes used in the Air Force, along with the associated characteristics of each.

Relating ERRC codes to parts included in WRSKs, recoverable spare parts are XD1, XD2, XD3 or XF3 items while EOQ spare parts are XB3 items. Both XB3 and XF3 items are additionally referred to as EOQ items by virtue of their management under the Air Force stock fund (22:p.1-1).

Recoverable WRSK items are also classified according to their indenture relationship. A Line Replaceable Unit (LRU) is an item that is normally removed and replaced as a single unit to correct a deficiency or malfunction (16:393). A Shop Replaceable Unit (SRU) is a component of a LRU that can be repaired at an intermediate repair facility once the LRU has been removed (17:627).

Another coding system that more specifically assigns management responsibility is Materiel Management Aggregation Codes (MMACs). MMACs are two-position alphabetic codes used to assign Item Manager responsibility for

TABLE 1

EXPENDABILITY, RECOVERABILITY, REPARABILITY, CATEGORY CODES

ERRC Designator	ERRC Code	Expendable	Reparable	Condemnation Level	Management/Characteristics
XD1	C	Yes	Yes	Depot	Serialized control and reporting system (SCARS)
XD2	T	Yes	Yes	Depot	AF recoverable assembly management system (AFRAMS)
XD3	L	Yes	Yes	Depot	AF recoverable assembly management system (AFRAMS)
XF3	P	Yes	Yes	Intermediate	Stock fund (except Munitions)
XB3	N	Yes	No	User	Stock fund (except Munitions)
ND2	S	No	Yes	Depot	AF equipment management system (AFEMS)
NF2	U	No	Yes	Intermediate	AF equipment management system (AFEMS)

management outside the normal Federal Stock Class (FSC) management (28:Vol.1, Part 2, pp.2-5 to 2-6). A separate MMAC is assigned to each segment or category of materiel to be managed as a separate logistics program (e.g., weapon/support systems, FSCs, engines, special technologies). EOQ items are managed with the next higher assembly if its design is governed by the next higher assembly and it is peculiar to that assembly. MMACs are only assigned to EOQ items when management with the next higher assembly removes it from its FSC management environment. MMAC codes are assigned on a selective basis; some items, as specified in AFLCR 23-30, are automatically coded while others must be petitioned and justified by the item manager and approved by the appropriate ALC or HQ AFLC, depending on the item.

WRSKs

As discussed earlier, WRSKs are air transportable packages of spares and repair parts that are designed to sustain planned wartime operations for weapon systems for a specified period of time, before wholesale resupply may occur. Each wartime tasked unit may be authorized WRSKs to support the programmed wartime activities of assigned combat weapon systems, combat support functions, command and control systems, and associated direct support equipment (29:p.2-1). The specific criteria used to determine which units are authorized WRSKs are contained in AFR 400-24,

and will not be discussed here. Nevertheless, HQ USAF/LEX authorizes kits via its annual WRSK/BLSS authorization and requirements letter (29:p.2-2).

Development/Review of WRSKs

When the WRSK/BLSS authorization letter indicates a new spares list is required, the System Manager (SM) will develop a recommended list of spares and spare parts applicable to the weapon system for approval and coordination by the using command(s). The composition of WRSKs will be tailored to the configuration, tasking, initial deployed maintenance capability, programmed arrival time of a follow-on maintenance capability, and programmed supply support concepts for the specific units assigned WRSKs (29:p.2-1). At the same time, the items and quantities selected will be the minimum necessary to support each major command's mission, as reflected in the War and Mobilization Plan (WMP) document (28:Vol.1, Part 1, p.14-32). Failure rates or maintenance data will be used in determining the range and quantities of items to be included. Normally, peacetime usage data, adjusted to wartime flying hours and sortie missions, provides the demand rates necessary to compute WRSK requirements. When such peacetime data is not available or appropriate (e.g., new weapon system), alternative data based on like-item usage, engineering estimates, prior or simulated combat experience, mathematical extrapolation, or other valid sources may be

used (21:p.2-1). After basic quantities are determined, a safety level, as specified in USAF WMP-1, is added (29:p.2-1).

Once initial WRSKs have been established, each spares list must be reviewed at least annually to ensure compliance with established item selection and computation policies, and to ensure continual update of item authorizations and supporting data (28:Vol.1, Part 1, p.14-38; 29:p.2-4). The WRSK reviews may be formal or informal, and should cover all recoverable items and selected EOQ items. Reviews for new weapon systems are held concurrently with initial provisioning conferences. All authorizations, as well as updates, are stored in the D040 system. In addition to these annual reviews, major commands must conduct a quarterly analysis to identify essential spare shortages expected to have the greatest negative impact on mission capability (28:Vol.1, Part 1, p.14-18; 29:p.1-5). This action is designed to lead to the timely resolution of identified critical shortfalls.

Supporting Maintenance Concept

The composition of a WRSK must be based on the maintenance capability deployed to the planned operating location. This requires establishing the planned maintenance concept when a kit is initially developed. WRSKs designed to be deployed with intermediate repair capability are

designated as Remove, Repair and Replace (RRR) kits, while those without are designated as Remove and Replace (RR) kits (29:p.2-1). In determining which concept to be used, tradeoffs must be made between equipment, personnel, spares, repair parts, and airlift requirements. The quantity of an item included in a kit is dependent upon the maintenance concept employed (21:pp.2-1 to 2-2). Although a kit may be designated as RR overall, it does not preclude the inclusion of RRR items (appropriately calculated) if the item can be easily repaired at the organizational maintenance level.

Composition of WRSKs

WRSKs contain both recoverable parts (investment items) and EOQ parts (expense items). The determination of which parts, and how many of each, to include in a kit depends on the type of item. WRSK requirements for investment items is computed by AFLC in conjunction with the using commands. On the other hand, WRSK requirements for expense items, which have ERRC codes "XB" and "XF," are computed by the using commands (29:p.2-1). Regardless of item type, each item included in a WRSK must meet the mission essentiality criteria listed in AFR 400-24.

Requirements Computation for Recoverable Items

WRSK quantities for recoverable items are currently computed using two different methodologies: conventional

computation detailed in AFLCR 57-18 and the D029 optimization system (28:Vol.1, Part 1, p.14-32). Negotiations with the using command(s) are required for both. The usage rates are negotiated when the D029 system is used, while the actual support quantities are negotiated when using the conventional method. In either case, the Recoverable Item Consumption Requirements System (D041) usage data, upon review by AFLC equipment specialists, will be the baseline on which negotiations take place. Nevertheless, using commands may provide base level usage data (T0-5 report in TAC) as a check or validation of the D041 data (21:p.2-1; 28:Vol.1, Part 1, p.14-32).

Conventional Method. The conventional method is a computation which is basically an expected demand formulation (30:4). The expected demand for each item is determined by multiplying the historical demand rate by the expected flying hour program by the quantity per aircraft (21:p.2-1). This is the basic formulation for a RR LRU. The formulations of RR SRUs and RRR items include necessary adjustments for the time it takes to set up maintenance capability. Each expected demand figure is multiplied by a stockage factor, which provides a safety level when it is set to a number greater than 1.0 (14:vii). The final quantity is rounded to the nearest integer, and there must be at least one of each item. AFLC policy (21:p.3-1) is

that the stockage factor will be 1.0, unless exceptions are approved.

Optimization Method. The optimization method employs a marginal analysis technique, which uses two weighted parameters: the expected number of backorders and expected NMC aircraft (30:3-4). The technique first computes the conventional quantities and evaluates them in terms of the two parameters. Then, using the marginal analysis procedure, it attempts to find a kit having the same level of support (in terms of the two parameters) but at a lower cost. The technique basically determines which items, when added to the kit, reduce the two parameters the most per dollar. It then adds these items until the new kit gives at least the same level of support as the conventional kit.

All items in a WRSK computed by this method are referred to as "optimized" (21:p.3-1). All items in this category are recoverable and must be labeled as "LRU" or "SRU." Manual adjustment may be necessary to compensate for known limitations of the D029 algorithm, such as the inability to cannibalize the item, redundant capabilities, and LRU/SRU relationships (21:p.3-1). Nevertheless, when adjustments are necessary, the conventional D029 quantity is the maximum allowable negotiated quantity.

In addition to certain limitations of the algorithm, there are some underlying assumptions of the D029 process which must be recognized:

1. Item failures are independent of themselves and each other.

2. A stationary Poisson probability distribution describes the demand process for each item.

3. Demands which cannot be satisfied from existing stock can be satisfied instantly through perfect cannibalization.

4. All items have the same essentiality for satisfactory equipment operation.

5. The entire scheduled flying program is flown regardless of the number of airplanes down.

6. Failures due to battle damage (including attrition) are not considered (14:8).

<u>Items Computed Outside D029</u>. Not all item requirements can be computed using flying hours; thus they must be computed outside of the D029 system (28:Vol.1, Part 1, p.14-40). Specifically, requirements computation for gun related items are based on rounds fired; wheels, brakes, landing gear and tires are based on number of sorties; support equipment is based on time; and for some items, peacetime usage is not indicative of wartime usage. These items are nonoptimized items and coded as "NOP" for input

to the D029 system (21:p.3-1). All EOQ items fall in this category, but are coded as "EOQ" for input to the D029; the using commands determine the quantities of these items.

Requirements Computation for EOQ Items

Requirements computation for EOQ WRSK items is not automated, nor is it as structured as the system for recoverable items. It is the responsibility of each major command to compute WRSK requirements for these expense items ERRC coded "XB" and "XF" (29:p.1-5). In TAC (20), the EOQ items to be included in a kit are determined by maintenance technicians at each base. It is purely subjective as to which items are considered mission essential by maintenance personnel. Note, however, that the mission essentiality criteria required by AFR 400-24 still apply. Because of the nature of the Poisson demand process, it is TAC's policy (20) that items with unit of issue "each" be excluded from a WRSK if the expected demand is only one or two items. Nevertheless, this policy has not been strictly enforced (as evidenced by the quantities in the D040 used for this research). As of June 1983, however, efforts have been made to ensure compliance with this policy (20).

Given a list of mission essential EOQ items to be included in a WRSK, computation of the required quantities is basically the same as for NOP recoverable items. Here also, the demand for EOQ items may not be based on flying

hours, but on rounds fired, sorties, time, or some other factor (28:Vol.1, Part 1, p.14-40). Basic usage data is obtained from TAC's WRSK Review Listing (T05 report) in the form of a Daily Demand Rate (DDR), then the expected demand is manually computed based on the appropriate demand generating factor. Furthermore, because of the benefit of buying many EOQ items in bulk quantities, additional adjustments are required if the unit of issue is something other than "each."

The AFR 400-24 requirement for an annual WRSK review also applies to EOQ items. Selected EOQ items, to include gun related and landing equipment, are reviewed along with recoverable items (28:Vol.1, Part 1, p.14-40). All other EOQ items are reviewed annually at base level; however, this review is staggered by six months from the recoverable WRSK review due to the extensive time involved in each review.

Inventory Theory

The Air Force maintains inventories of both recoverable and EOQ items, for peacetime and for anticipated wartime needs (WRM). Peacetime requirements for EOQ items are determined by the EOQ Buy Computation System (D062), which makes tradeoffs between the cost of carrying an item in inventory and the cost of reordering. This system is not used to determine WRSK requirements, however, so

it will be excluded from further discussion in this research. The inventory theory presented in this chapter deals with recoverable items, and is the basis for recoverable inventory models used to determine both peacetime and wartime requirements. Nevertheless, as will be shown, this same theory can be applied to mission essential EOQ items for purposes of WRSK capability assessment.

Given the requirement to maintain a certain level of aircraft availability (readiness) and recognizing the nature of physical equipment to deteriorate and malfunction, the Air Force has at least two alternatives to maintain the desired readiness level. First, it could procure enough excess aircraft (at tremendous cost) to allow for mechanical failures and still have sufficient aircraft to meet mission requirements. Surely the more cost effective and practical alternative is to maintain inventories of mission essential spare parts based on the probability of their failure. From an inventory perspective, the only thing that grounds an airplane is the lack of mission essential parts. Theoretically, then, any level of readiness can be supported if spare part inventories are high enough.

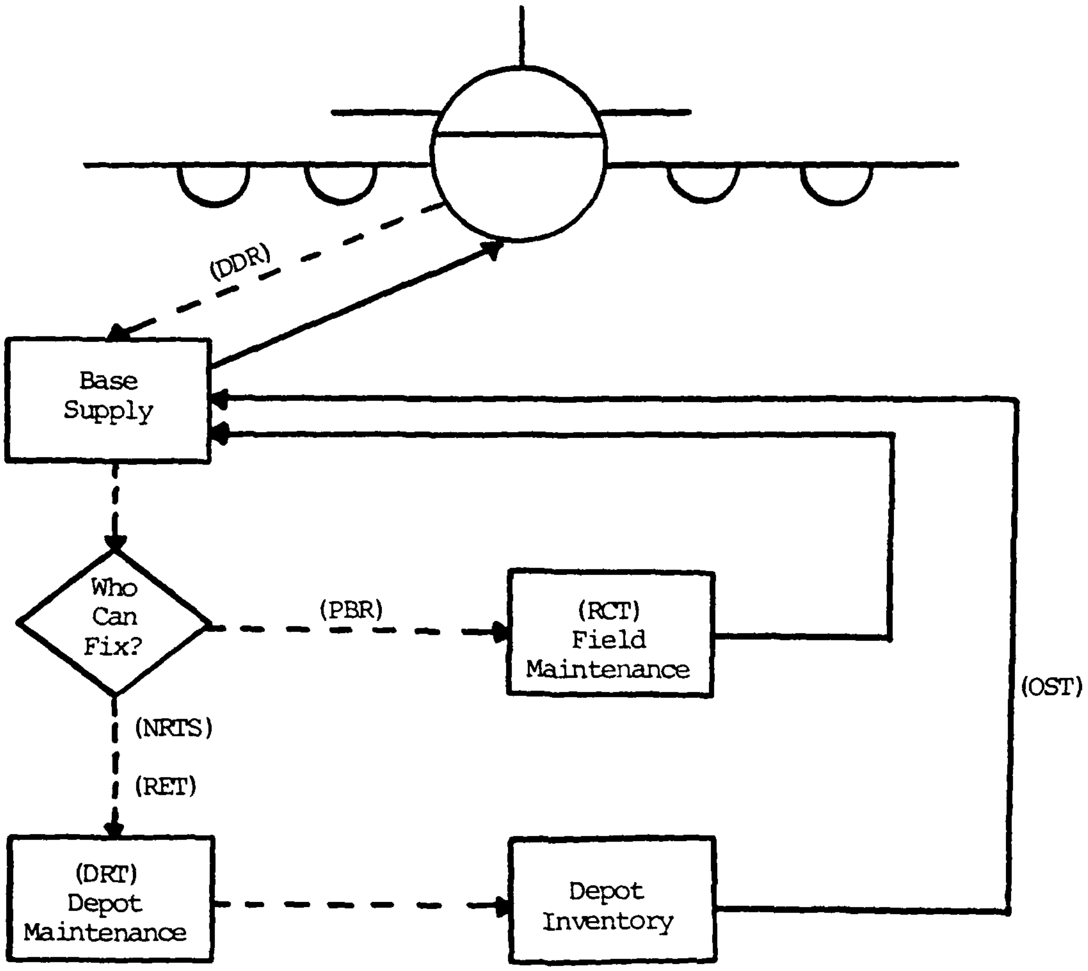
Inventory systems are designed to determine, among other things, what and how much to order. Generally, the essentiality and rate of failure of each part are considered when determining what to order. Selecting how much to order typically involves a tradeoff of some sort. In the case of

recoverable items, which are characteristically high cost and relatively low demand items, the tradeoff is between inventory costs and the level of aircraft availability. Once again, this argument can hold true for mission essential EOQ items.

The basic principles of recoverable item management are presented in the following paragraphs. But first, Figure 1 provides a diagram and definition of terms necessary for the discussion.

Parts fail on an aircraft at a daily rate equal to its DDR. When a part fails it is removed and sent to base supply where a replacement is hopefully in stock. If a replacement part is in stock, an exchange takes place. The failed part can now follow one of two possible routes for repair. A certain percentage of parts (PBR) can be repaired at the intermediate level, where each will take a particular amount of time to repair (RCT). Thus, the DDR x PBR x RCT is equal to the number of parts tied up in intermediate level maintenance. This is known as a pipeline quantity.

The remaining number of parts which cannot be repaired at the intermediate level (NRTS) will be sent to depot for repair. This involves a shipping time to the depot (RET), and, again, a particular time to repair the parts (DRT). However, because the depot maintains an inventory of repaired parts, it can issue a replacement part immediately and replace this loss with the part



Key

--- = Flow of broken parts
—— = Flow of good parts
DDR = Daily Demand Rate
PBR = Percentage Base Reparable
NRTS = Not Reparable this Station (1-PBR)
OST = Order and Ship Time
RCT = Repair Cycle Time
RET = Retrograde Time (shipment to depot)
DRT = Depot Repair Time

Fig. 1. Recoverable Item Management

undergoing repair. For this reason, RET and RCT are not considered in determining the depot pipeline quantity; it is generally assumed the depot will have stock on hand. Thus, the depot pipeline quantity is equal to DDR x NRTS x OST, since the only delay involved in getting a part from the depot is the order and shipping time from the depot. By adding the intermediate level pipeline and the depot pipeline quantities together, the result is the total number of parts tied up in maintenance. This total pipeline quantity is equal to DDR ((PBR x RCT) + (NRTS x OST)).

Given a system with no spares, as parts fail at their respective DDRs, the pipeline will quickly be filled up with parts off of the aircraft, resulting in a corresponding number of grounded aircraft. Therefore, the first rule of a recoverable item system is to buy sufficient spares to fill pipeline quantities, which remains a fairly constant number as long as the parameters of the pipeline formulation do not change. Theoretically, under this condition, as one part fails on an aircraft, another is just leaving one of the repair cycles to replace it. However, RCTs are not point estimates, but they actually follow a normal distribution of repair times. Thus, if the RCT is a mean value, then based on a normal distribution, 50 percent of the time a replacement part will not be available. Therefore, it is preferable to have the number of spares something greater than the pipeline quantity. The number

of spares exceeding the pipeline quantity will determine the actual availability of the item. The availability associated with a given number of parts can be calculated from a normal distribution table.

This same theoretical foundation can be adapted to WRSK related scenarios. If no depot resupply will be available, then an infinite OST can be specified. In this way, once WRSK assets are depleted, those which would normally be NRTS would not be received within the thirty-day deployment period. Similarly, WRSKs may be designed with intermediate repair capability (RRR kit) or not (RR kit), depending on the maintenance manpower and equipment to be deployed with a unit. Therefore, for RR kits, where repair capability will not be available, an infinite RCT can be specified thereby precluding the availability of any repaired parts when WRSK assets are depleted. Similarly, selected variables in the formulas can be manipulated to model a wide range of scenarios that may be required by the user.

Inventory Policy

The Air Force uses an (S-1, S) policy to order recoverable parts (7:10). The decision of concern under this policy is what level of spare stock (S) to maintain to protect against stockouts. Once set, S becomes the pivot point of the inventory system. Whenever the base level

stock drops below the quantity S, an order is placed to the appropriate echelon for a quantity to bring the stock on hand, plus on-order, minus backorders equal to the quantity S.

The local supply system of recoverables is dependent on transportation and maintenance services. Whenever a recoverable part fails and the base is authorized and equipped to repair the part, it traverses the base repair cycle and is returned to supply as serviceable stock. If it cannot be repaired locally, it is forwarded to the appropriate echelon of maintenance. At the same time, a replacement is ordered from that echelon in order to keep the base stock equal to quantity S.

Inventory System Performance Measures

This section describes a group of system performance measures which are used in assessing inventory and service policy as they relate to organizational goals and performance. Although the list is not exhaustive, it does highlight the more popular "measures of merit" in the Air Force today.

Fill Rate

The fill rate is defined as "the percentage of demands that the supply activity at the lowest echelon is able to fill without delay from on-hand stock [17:291]." It can be calculated by dividing the number of demands

filled from stock on hand (those not backordered) by the total number of units demanded in the same time period. Most inventory models interpret the fill rate as being the probability that a component will be available when a demand is placed (4:26; 5:16).

Average Backorders

Average backorders is a measure of the expected number of backorders per time period. A backorder is defined as "that portion of stock which is not immediately available for issue to the requisitioner and will be recorded as commitments for future issue [17:83]," or simply as a due-out from base supply. The average can be determined by measuring the number of due-outs at a fixed time every day and averaging these numbers together over the course of the year. An alternative method of calculating the average is to measure how many days it takes to satisfy each backorder during the year, dividing by 365. Brooks, Gillen and Lu (2:2) point out that average backorders have an advantage over fill rate as a performance measure; they can provide information about how long backorders last as well as how many occur.

Operational Rate

Operational Rate (OR) is the probability there are no backorders at any given point in time. This implies there are no aircraft missing parts at the given point in

time. To calculate OR, observe the number of days with no backorders during the year, and divide by 365. According to Brooks, Gillen and Lu (2:3), the advantage of OR compared to fill rate and average backorders is that it can be directly related to the supply system's effect on operations. The disadvantage, however, is that it does not distinguish the number of aircraft with backorders; only that at least one aircraft had a backordered part on a given day.

Assuming each item considered is essential to aircraft operation, the OR becomes the probability there will be zero NMCS aircraft. A further variation of the OR is operational rate after K cannibalizations, where K is an integer number of aircraft used as a source for cannibalizing parts. In other words, it is the OR after K airplanes are allowed to serve as a supply of spare parts to fill backorders. Assuming shortages will be consolidated on as few of these K aircraft as possible, the operational rate after K cannibalizations becomes the probability there will be no more than K NMCS aircraft.

<u>Average NMCS Aircraft</u>

NMCS is a measure of the average number of aircraft not mission capable due to the lack of spare parts (11:478). It is calculated by summing the number of NMCS days for each aircraft, and dividing by 365. An alternate method is to observe the number of NMCS aircraft at the same time each

day, and averaging these numbers over a year. NMCS is the best of the four measures of supply performance because it measures the extent to which the supply system cannot maintain operational readiness (2:5). This is where the treatment of cannibalization comes into play. The NMCS measure is predicated on the assumption of whether or not cannibalization is assumed to take place (full-cann mode versus no-cann mode).

Full-Cann NMCS. This performance measure requires the additional assumption that when demands cannot be satisfied from stock on hand, the parts will be removed (cannibalized) from NMCS aircraft so that parts shortages are consolidated on as few aircraft as possible. The probability of K or less NMCS aircraft is used to predict the expected number of NMCS aircraft.

No-Cann NMCS. Logistics Management Institute developed a model which gives a measure of aircraft availability (7:16). The measure is the probability of any aircraft being available at a random point in time. The complement of this availability is NMCS rate. This measure of NMCS assumes cannibalization does not occur.

Partial-Cann NMCS. Dyna-METRIC has the capability to compute the probability that at any point in time, there will be no backorders, given that if one aircraft was

nonoperational, it would represent a supply source for all future backorders occurring within the fleet. This is referred to by Hillestad (8:33) as an instantaneous cannibalization policy. However, most models ignore this time-dependent feature of employing conditional probability (7:16). Hillestad (8:35) expands this concept by assigning full or no-cann assumptions to specific LRUs rather than all of the spares within the system. He terms this measure as NMC with partial cannibalization.

Cannibalization

Cannibalization provides an additional source of spare parts in the face of supply shortages/disruptions, or transportation delays. Cannibalization is a common practice in many service systems, especially in more modern ones where the equipment to be repaired is highly modular and thus interchangeable in a short period of time. In other than these ideal conditions, however, cannibalization carries a price. It may result in the expenditure of maintenance resources (especially manpower) above what is normally authorized to accomplish mission requirements (26:p.1-5). Man-hours are typically doubled since two components must be removed and two installed instead of just one. Not all parts can be cannibalized, however. Many factors determine the feasibility or practicality of cannibalizing a particular component, such as engineering design,

location on board the aircraft, potential risk of damage from removal, reparability, and maintenance capability/ availability. Even among those parts considered to be cannibalizable, there is a risk of damaging the component, which may create an additional NMCS airplane. On the other hand, there are circumstances which warrant cannibalization. Myette (12:47-58) identifies seven reasons why squadrons cannibalize. Some of these may not be justifiable, depending on one's point of view. The most obvious reason has been previously identified as materiel shortages. Supply response times that exceed critical launch windows create the same situation as a materiel shortage since the necessary part lacks time utility. Readiness rates are so highly emphasized they have become a career promotion factor for commanding officers. This frequently leads to consolidation of losses merely to achieve target readiness rates. The most valid reason for cannibalization is to meet operational commitments. When there is a high probability of stockout of specific parts due to supply/production problems, cannibalization can avoid the risk of a stockout, and prevent the loss of sortie generation. Often, troubleshooting systems beyond or without self diagnostics require cannibalization of suspect components. Finally, where maintainability is designed into modern systems, cannibalization is so quick and easy (less than fifteen minutes

elapsed time) that waiting for supply system response is not an acceptable alternative.

Inventory Models

Steady State versus Dynamic

Most probabilistic inventory models for recoverable item stockage were developed for systems in a steady state (i.e., the demand process is stationary or constant over time). As reported by Hillestad and Carrillo (6:1), the assumption of steady state conditions (constant average demand rate and service rate) is both reasonable and convenient during peacetime. Thus, steady state assumptions are used extensively in Air Force inventory stockage models. Even during peacetime, however, the environment is not always stationary over time. Flying activity increases abruptly as a new type of aircraft is introduced and decreases as it is phased out of service. The well-known work of Feeney and Sherbrooke (6:1) regarding an (S-1,S) inventory policy has proven to be cost effective in establishing recoverable item's reorder point (7:10). Using Palm's Theorem (8:8), this inventory policy basically describes how many components will be in the various pipelines of a component repair/inventory process, assuming a Poisson arrival and exponential probability distribution for mean time between failure for components (16:9). However, the restriction of a steady state assumption limits

its usefulness during nonsteady or wartime conditions (5:8; 8:8-10). Under such circumstances, steady-state models inaccurately estimate stockage requirements and supply performance. Thus, the models either overstate or understate the capability to support a projected sortie rate or flying hour program (11:1).

In an effort to deal with steady state restrictions, RAND expanded Palm's theorem in 1976 to include not only the mean repair time used in the steady state process, but also its respective distribution or variability about its mean. This will capture the dynamic demands and transient behavior generally present during flying hour and sortie surges. RAND then added the concept of time into this function thus allowing for time-dependent flying scenarios as well as time-dependent repair (8:8-9). This was a much needed improvement in the mathematical representation of real-world events. For example, at the onset of a conflict, demands for critical components may increase very rapidly (nonsteady state and time-dependent) relative to the previous peacetime activity. Meanwhile, initial service rates may be near zero as the deployed units transport to forward operating locations. As time progresses, however, repair time would gradually increase to its full wartime service capability. Thus far, the theory presented fails to recognize conditions of dependency among cannibalization, aircraft attrition, available equipment and

personnel, and multi-echelon or different organizational levels of repair. However, this theory is the foundation for which almost all inventory stockage models are derived.

Conventional Air Force Base Level Stockage Model

The Conventional Air Force Base Level Stockage Model is a steady state model that computes stock requirements for individual bases. This model, like all others, computes a pipeline quantity S. A "pipeline" contains some of the total inventory of parts available. Typical pipelines consist of components awaiting repair, those being repaired, those held in inventory, those in transport to or from another echelon of maintenance, and those partially repaired but awaiting parts (8:3). The objective is to calculate an S sufficiently large to fill the pipeline and still have sufficient components to maintain aircraft availability. The weaknesses of the model are: it treats each item independently of all others, does not consider cost, and does not provide a measure of system performance (7:21). This model is currently used by most bases in the Air Force, but is being replaced with a version of METRIC.

Base Stockage Model

The Base Stockage Model was developed by RAND in the mid-sixties and examines all stock items within a stockage location concurrently. This technique considers

tradeoffs between items as a minimization function subject to budgetary constraints. Its purpose is to minimize the number of backorders for a given dollar amount. A marginal analysis technique determines what mix of stock will provide the lowest backorder level. However, like the Conventional model, it ignores demand variability but does seek to optimize system performance (7:21).

METRIC

The Base Stockage Model improved previous inventory management methods; however, it was never fully implemented. Sherbrooke expanded the model to include depot level supply and to calculate requirements for the entire Air Force supply system at one time. This model is known as the Multi-Echelon Technique for Recoverable Item Control (METRIC). METRIC computes stock requirements and redistributes stock with the objective of minimizing base backorders subject to the investment constraint (10:473). Depot backorders are significant only to the extent they affect base backorders. METRIC does not consider the effect cannibalization has on the performance of the inventory system, thus it tends to overestimate stockage for systems which allow cannibalization (6:3). The Air Force is currently implementing METRIC into its inventory management system.

MOD-METRIC

The METRIC model had the tendency to heavily order inexpensive components because purchasing these items decreased backorders more. Muckstadt (10) overcame this problem by incorporating an indenture relationship between components and subcomponents. Main components that fail (LRUs) are removed on the flightline and forwarded to a local shop. There the SRU that caused the LRU to fail is removed and replaced with a new one. MOD-METRIC assumes LRUs will degrade mission capability while SRU backorders only delay repair of LRUs. With this improvement, MOD-METRIC minimized backorders of LRUs only, still subject to an investment constraint on all LRUs and SRUs (6:472-475). This represents the first step towards recognizing true supply system behavior, especially as it relates to cannibalization. However, MOD-METRIC, like all previous models mentioned, does not consider the effect of cannibalization. Therefore, it also overstates stock requirements for systems which allow cannibalization (6:3).

LMI Availability Model

This model was developed to express military capability of weapon systems. Military capability refers to the availability of weapon systems to meet their mission requirements. The LMI Availability Model exploits two existing Air Force systems: the Air Force Recoverable Item

Classification System and METRIC inventory model (9:4). The classification system is used to identify mission essential parts. The LMI model is an extension of the METRIC model. Rather than minimizing backorders, however, the METRIC-LMI model minimizes NMCS aircraft, thereby maximizing aircraft availability (9:12).

The objective function of all of the models prior to the development of LMI has been to minimize backorders. The models have not addressed cannibalization because it was irrelevant. In these models the number of backorders would be the same whether it cannibalized or not. The only effect cannibalization would have in one of these models would be to consolidate the broken parts into fewer airplanes (there would be the same number of backorders, but they would all be located in fewer planes). The objective function of LMI, on the other hand, is to maximize availability. In this type model, consolidating broken parts into fewer airplanes would increase the number of aircraft available to fly their missions. Thus, cannibalization becomes an important factor. The LMI model assumes no cannibalization occurs, which means it will overestimate stock requirements (7:3).

Dyna-METRIC

The ultimate question constantly asked by senior Air Force managers is: How many aircraft will be available

for combat? The steady state models simply cannot answer that question. This motivated RAND to develop Dyna-METRIC (13,000+ lines of FORTRAN code), a dynamic nonsteady state inventory stockage model, to assist logistics managers in answering that paramount question. Dyna-METRIC is capable of computing stock levels, the expected number of NMCS aircraft, and the probability of achieving no more than a target NMCS level.

The mathematics behind Dyna-METRIC are complex and beyond the scope of this study. The Air Force Logistics Management Center and others have conducted extensive verification testing of Dyna-METRIC (5:10). The results thus far have shown to be quite promising (5:VIII).

Dyna-METRIC views an aircraft to be nothing more than a collection of spare parts, each of which is waiting to fail. Once a critical part fails and a replacement part is not readily available, the aircraft is NMCS until such time as the part is received. When operated from a full cannibalization mode, the model searches for other aircraft that are NMCS from which to obtain parts. It should now be clear just how the act of cannibalization augments the pipeline/resupply of spare components. Having an aircraft available from which spare parts may be obtained can have a dramatic effect on aircraft readiness, especially for tactical missions where time is so critical.

Dyna-METRIC can handle a variety of configurations from a single base to a multiple-base theater. Each base possesses some intermediate repair capability and is usually augmented by a Central Integrated Repair Facility (CIRF). The depot, of course, represents the ultimate source for spares (5:12; 6:4). Dyna-METRIC (version 4.0) has the capability to model a situation where each base/CIRF has its own cannibalization policy. Version 4.2 has expanded this capability to include each LRU as having its own treatment of cannibalization (6:43). Note that the treatment of cannibalization remains an either/or condition, but allows greater selectivity as to which parts receive which treatment. However, further specific treatment to the SRU level has not yet been developed; only global treatment is currently available. It remains unclear as to what level of specificity is needed to improve the reliability of performance measures.

Although Dyna-METRIC has come a long way in its ability to model real-world events, users must be aware of the many inherent assumptions regarding probability distributions, independence of variables, failure and repair of components, flightline capability, and allocation of resources (6:6). Each of these assumptions, along with input/output configurations, is examined in detail in Chapter III. It will suffice at this point to simply say

that Dyna-METRIC is a valuable management tool, even with its inherent assumptions, to study the Air Force logistics system.

Summary

This chapter dealt with the purpose and makeup of WRSKs and their relationship to aircraft readiness. Also, the fundamental inventory theory inherent in almost all Air Force inventory systems was explained as a basis for understanding the operation of recoverable inventory models, which are used to assess WRSK performance capability. Inventory system performance measures were then discussed, followed by a historical development of Air Force inventory stockage models. The models presented started simple and became more complex by building on their predecessor until they reached the peak of sophistication found in Dyna-METRIC.

Any inventory model seeks to buy the optimal mix of spares for a given amount of money. The Air Force, however, needs to answer the paramount question: How many aircraft will be available for combat (as it relates to the logistics system)?

The objective of this study was not to test the mathematical logic underlying WRSK requirements computations nor the differential and integrated equations used in the various models. Rather, it was to determine the impact, if any, of WRSK EOQ items on aircraft readiness;

and secondarily, to address the impact cannibalization treatment has on the magnitude of this impact (i.e., the impact cannibalization treatment has on mission readiness).

Past research in both of these areas is virtually nonexistent. Absolutely no research was found that dealt with the impact of WRSK EOQ items on aircraft readiness. Regarding cannibalization, a few studies, Myette (12:1) and Solomond (18:1), view cannibalization as either a cost/benefit tradeoff because of the wasted maintenance manhours, or as a viable cost effective alternative to logistic system failures. These areas of study, although important in their own right, tend to view cannibalization in terms of management cost efficiency. In contrast, this study views cannibalization in terms of mission effectiveness, which necessarily assumes that decisions regarding cannibalization and stockage requirements have already been made by the onset of conflict.

CHAPTER III

RESEARCH METHODOLOGY

Overview

The methodology developed for this research consists of identifying selected EOQ items with ERRC code XB3 contained in a specific F-16 WRSK kit, and then determining what impact, if any, they have on aircraft readiness. Three items were needed in order to carry out this methodology. First, a model was needed that would adequately represent real-world contingencies so that its results would be useful in evaluating current Air Force inventory stockage policies and weapon system capability assessment evaluations. RAND's Dyna-METRIC model was selected as the evaluation tool because of its sophistication regarding the treatment of cannibalization, its ability to model real-world events, and its capability to assess aircraft availability rather than simply computing the expected number of backorders, as most recoverable models do. Second, a realistic data base and scenario were needed in order to model the performance of an active Air Force weapon system under realistic, anticipated wartime environmental conditions peculiar to the assigned mission of that weapon system. An F-16 data base and wartime scenario provided by HQ TAC/LGYT satisfied this requirement. Lastly, an

experimental design was needed that would fully answer the research questions proposed. The first step of the design established a baseline probability of aircraft readiness for recoverable F-16 WRSK items exclusively. Next, the selected EOQ items were added to the original recoverable data base to determine the effect they have on aircraft readiness. Initially, the EOQ items were treated as non-cannibalizable. However, one additional step was performed treating them as fully cannibalizable in order to assess the impact that the assumption of cannibalization has on model outputs. The research question is answered by the systematic execution of this design using Dyna-METRIC (version 4.2), the F-16 WRSK data base, and wartime scenario. The results are presented in both tabular and graphical format for easy interpretation.

Evaluation Model

Dyna-METRIC was used as the evaluation tool for this research. It is a validated, state-of-the-art recoverable model capable of both stock computation and performance evaluation. Dyna-METRIC has been used at Ogden ALC and Headquarters, AFLC to study USAF F-4 and F-16 aircraft readiness and supportability, and by TAC to study the effect of several repair and supply strategies affecting F-15 tactical squadrons (8:IV).

Dyna-METRIC is a versatile mathematical inventory model which employs dynamic queueing equations for the purpose of studying the transient behavior (e.g., sortie rates, time-dependent failure rates, phased arrival of repair teams) of component-repair inventory systems under time-dependent operational demands. Dynamic features such as these allow researchers to conveniently study a variety of "what if" questions which provide the logistics manager the ability to look at almost any potential combat environment and determine the shortfalls caused by inadequate logistics support. Dyna-METRIC is a powerful evaluation tool that reduces the complexity required in setting up experimental designs. Because it is an analytic model, rather than simulation model, only one set of outputs is possible for a given set of input parameters. The outputs, however, are given in probabilistic terms. In contrast, Monte Carlo sampling used in simulation models would necessarily produce different output results for each and every simulation, even if the input parameters remain unchanged. This would necessitate several runs for each given matrix cell in the design in order to satisfy statistical sampling requirements. Therefore, experimental design using Dyna-METRIC closely parallels the case study approach where each cell in a matrix design represents a single case study. This approach greatly reduces the time and resources required for a comparable confidence level.

Dyna-METRIC is capable of handling a variety of aircraft flying programs. These flying programs are based on aircraft activity specified for each operational location. It can model up to ten bases, including both depot and CIRF; order, shipping, repair, and transportation delays; aircraft and component attrition rates; phased aircraft arrivals; and aircraft turnaround times. These parameters add realism to the scenario by including the interdependencies among these variables. Dyna-METRIC is also capable of handling indentured relationships among components, with each LRU and SRU having its own representative failure (demand) rate. Dyna-METRIC predicts when a particular LRU will fail and whether its failure is dependent on the failure of a particular SRU. The specific cannibalization treatment of a failed LRU is taken into account when Dyna-METRIC determines the cost optimal mix of spares needed to maintain a specific readiness rate at each location. When operated in a stock computation mode, Dyna-METRIC first fills the CIRF/depot pipeline and then minimizes the cost of stockage at each base while achieving a desired confidence level that the NMCS rate will meet a specified target (e.g., p[NMCS rate = 5 percent of aircraft] = 80 percent). For this thesis, the authors used HQ TAC's specified 80 percent probability that there would be 5 percent or fewer NMCS aircraft at each base. When operated in a performance evaluation mode, Dyna-METRIC identifies the

parts that caused the system to fall short of the desired target probability and NMCS rate. The objective of this model is to avoid the degradation of sortie generation because of a shortage of functioning components. The concept of cannibalization comes into play when the number of components in repair and transportation pipelines is greater than the local spares supply of these components. If a particular LRU is cannibalizable, then a newly grounded aircraft can immediately return to a serviceable condition by cannibalizing the needed part from another grounded airplane with an operable LRU.

Model Assumptions

It is axiomatic that any model, including Dyna-METRIC, must necessarily make simplifying assumptions in their mathematical relationships between critical elements; otherwise, the model would become overburdensome to the point of impracticality. Although Dyna-METRIC maintains the capability to model real-world events to an appreciable degree, it nevertheless does have its limitations. For a more in-depth treatment of Dyna-METRIC's underlying mathematical derivations and assumptions, the reader is referred to RAND's publication R-2785-AF, July 1982 (6). The Dyna-METRIC model assumes:

1. Average repair times are stationary about their mean.

2. Given the necessary parts and equipment are available to repair a component, repair of the component will never be delayed due to lack of service capability (i.e., there is infinite service capacity).

3. All echelons of resupply are assumed to have identical repair processes (i.e., repair times are identical).

4. Components require testing prior to repair. That is, components can queue based on available test equipment.

5. Demand for LRUs is instantaneous, but the demand for SRUs is not discovered until the parent component is received and tested at the repair facility.

6. Aircraft are "semi-homogeneous" for any given base. The model assumes that aircraft components are interchangeable given cannibalization is permitted.

7. Sortie rate is unconstrained by flightline limitations (e.g., personnel, weather).

8. Aircraft components fail at a given rate based on flying hours only.

9. The daily demand rates follow a Poisson probability distribution and are a function of time for each pipeline.

10. The repair probability function is independent of the probability distribution generating the demand rate.

11. Under cannibalization, the model assumes the ability to instantly consolidate shortages onto the smallest number of airframes at no cost.

12. Lateral resupply is prohibited.

Research Data Base and Scenario

An F-16 D029 Computation List (WRSK Kit serial number 0F016A0T2400) was obtained from HQ TAC/LGYT. This kit contains 246 recoverable items (239 LRUs and 7 SRUs) and is stocked at authorized levels specified in the D040 dated November 1982. Also, a special D040 selected records list consisting of 1865 line-items was obtained, which provided a current listing of authorized EOQ items found in the specified WRSK kit. A WRSK Review Listing (T05 report), dated 1 Jun 83 was obtained from the 474th TFW located at Nellis AFB, Nevada. This report computed historical demand/usage data (DDR) for selected EOQ items based on a 180-day period. QPA data on those same selected EOQ items was obtained from the Integrated Logistics Data File at Ogden ALC, Utah.

The generic F-16 scenario (unclassified) used for this research was also provided by HQ TAC/LGYT. Although simple, it nevertheless represents realistic wartime conditions peculiar to tactical aircraft missions. The scenario consists of a single base supporting one wing (twenty-four aircraft) with a flying hour surge of 2.8 sorties per aircraft, per day for the first seven days, decreasing to 1.1

sorties for the remaining twenty-three days. Sortie duration and turnaround time were both held constant at 1.8 hours and 3.5 hours, respectively. The wing operates solely from the WRSK kit using a "RR" maintenance concept and does not receive depot resupply of needed parts for the entire thirty-day period. Furthermore, all other variable input factors (e.g., aircraft attrition, *CIRF* resupply, test stands) are not considered in this scenario so that results can be easily interpreted.

Data Preparation/Manipulation

Currently, the Air Force does not specifically track the information necessary to readily determine the cannibalization feasibility, demand per flying hour, or QPA for XB3 WRSK assets. This constraint, along with the size of the data base (1865 items) and time restrictions involved in collecting the necessary information from various sources, required that a methodology be developed to prepare, screen, and manipulate the data into a workable size and form.

The first step in screening the data involved examination of cannibalization feasibility for individual components. As was mentioned earlier, for items which can be cannibalized, there is an additional supply of spare parts whenever an aircraft is NMCS. Therefore, the potential impact of the WRSK stock levels on aircraft readiness should be less for these items, all other things being

equal. For noncannibalizable items, however, once the stocked parts are depleted, any further failures caused by those parts will reduce aircraft availability permanently, or at least until resupplied. Therefore, in the interest of reducing the data base, while retaining only the more critical parts in the WRSK, only those EOQ items thought to be noncannibalizable were included in the analysis. The breakout of noncannibalizable parts was based on ERRC codes. The decision rule was first to include only those items with ERRC code designator XB3, since only XB3 items are designated as nonreparable. Based on the broad assumption that nonreparable items are generally not cannibalizable, only XB3 items were included for analysis, while XF3 (EOQ reparable) items were discarded. It was felt that the XF3 items would, in most cases, be cannibalized in real-world contingencies, thereby lessening their potential impact on aircraft readiness. After this initial screening, the data base consisted of 1534 XB3 items. Additional measures were needed to further screen the data. As it turned out, a limitation on obtaining QPA data provided the breakout needed. Because of the limited manpower and computer terminals accessing the ILDF data bank at Ogden ALC, it was infeasible to run individual inquiries on 1534 items. Likewise, it was not practical to simply generate QPA data on all F-16 parts, as there are over 400,000 of them. However, it was possible to write a

FORTRAN program to extract all items with specified MMACs. This further reduced the data base to 304 EOQ items, a reasonable size for Ogden's workforce. Further, the breakout by MMAC included those items which are generally weapon system specific, and excluded the preponderance of common hardware items (e.g., nuts, bolts, cotter pins, light bulbs) which the authors desired to exclude for reasons of cannibalization feasibility and questionable mission essentiality. (See Appendix B for a listing of MMAC codes included in this research.) It was felt that common hardware items such as these could actually be cannibalized in a wartime environment, thereby reducing their potential impact on aircraft readiness. The authors felt that a data base of 304 MMAC coded EOQ items would be representative to the extent necessary to determine the effect that current stock levels of EOQ items have on aircraft readiness.

Given that a data base of 246 recoverable items from the D029 system and 304 noncannibalizable EOQ items from the selected D040 system were available, two data manipulation problems remained. The D029 contains all the information necessary to assess recoverable items using Dyna-METRIC (see Appendix C). However, since EOQ items have never been analyzed by recoverable inventory models, the D040 does not contain all the necessary information to execute Dyna-METRIC (see Appendix D). The information

needed on the EOQ items was demand per flying hour and QPA.

Obtaining historical demand data for EOQ items was achieved through a T0-5 report provided by Nellis AFB, Nevada (see Appendix E). This report listed the weapon system DDR for each item caluclated over a 180-day period. The number of flying hours corresponding to this same time period was obtained via TAC's Working Paper for Maintenance Indicator Briefing dated 15 July 1983. From this information, the demand per flying hour could be hand-calculated for each EOQ item with the following formulas (17):

$$\text{Mean Time Between Demands (MTBD)} = \frac{\text{Total Hours Flown} \times \text{Quantity Per End Item}}{\text{Total Demands}}$$

where total demands = DDR x 180 days and demands per flying hours = 1/MTBD. (See Appendix F for a sample computation.)

The problem of determining QPA was not as easily resolved. As far as the authors could find, the only source of consolidated, computerized QPA data for EOQ items in the Air Force is in the ILDF data bank at Ogden ALC, Utah. QPA information can be extracted by individual inquiry or by computer program. When individual inquiries are done by national stock number (NSN), the QPA is first listed at the lowest level of indenture (see Appendix G). From here, the part can be traced upward through next

higher assemblies to determine the Quantity per End Item (QPEI), or total quantity per aircraft, which is the value needed for Dyna-METRIC. A QPEI figure is not listed separately in the ILDF, and must be determined by this method.

When QPA data on the NSNs is extracted from the ILDF via FORTRAN programming, as was done for this research, only QPA for the lowest level of indenture is listed. Although this did not provide consolidated QPEI data, it did provide the information needed to determine the QPEI. Actually, QPEI is equal to QPA when all next higher assemblies have respective QPAs equal to one, and according to Mr. Clyde George, a Logistics Data System Specialist, this is usually the case for EOQ items (4).

Although using QPA data for QPEI would be relatively safe for the reason just mentioned, it is important to realize the effect of next higher assemblies with QPAs greater than one. Table 2 and the supporting example should clarify the effect.

TABLE 2

THE EFFECT OF HIGHER ASSEMBLY QPA ON QPEI

Indenture Level	Part Number	QPA	QPEI
3	789	2	2
2	456	1	2
1	123	4	8

As can be seen, if part 789 at the highest level of indenture (3) has a QPA equal to 2, then the QPA for all lower indentures has to be multiplied by 2 to get a true QPEI. Instances of higher assemblies with QPA greater than 1 could not be determined from the batch data obtained from the ILDF, and thus they represent sources of potential error. The effect of this error may significantly affect the performance measure used in this research (NMCS). If the actual QPEI is greater than that used in the model, the demand rate for that item will be greatly underestimated, resulting in a lower NMCS rate. Conversely, if actual QPEI is less than the value used in the model, the demand rate will be overestimated, resulting in a higher NMCS rate.

Approximately 10 percent of the EOQ items were randomly selected for individual computer inquiry which traces each part through all levels of indenture. It was found that the second level QPAs and higher were indeed 1, thus giving further credence to this methodology and providing greater confidence in the QPEI data used.

One final note, it is generally HQ TAC's position to use a full-cann treatment in Dyna-METRIC analysis. Therefore, the recoverable items received full-cann treatment while the EOQ items received both the no-cann and full-cann treatment.

Experimental Design

Locating, preparing, screening, and manipulating the data proved to be the major portion of this research. On the other hand, the experimental design developed for this research consisted of a simple, straightforward four-step process.

The first step was to establish a baseline performance measure (NMCS) for a thirty-day period exclusively for the recoverable items (designated as full-cann). This step represents the current thinking of Dyna-METRIC WRSK analysis. The second step was to determine the NMCS rate for the EOQ items alone (designated as no-cann). This step isolates the support provided purely by the EOQ items. Since Dyna-METRIC (version 4.2) has the capability to analyze both full-cann and no-cann parts within a single run, the third step required adding the EOQ items (no-cann) to the baseline recoverable data base (full-cann). The fourth and final step of the design was to change the cannibalization treatment of EOQ items from no-cann to full-cann, still being combined with the recoverable (full-cann) data base.

With this design, any change from the previously established baseline performance measure can be directly attributable to the addition of EOQ items, thereby answering the proposed research question: *Given an aircraft readiness rate based on recoverable WRSK items only, what*

is the impact of EOQ WRSK items, at current authorization levels, on that established readiness rate? It should be noted that the effect of EOQ items on aircraft readiness rates determined in the combined runs may or may not be the same as that determined for the isolated run of EOQ items alone. The combined runs, nevertheless, provide the estimates of the level of readiness provided by all items in the WRSK.

Research question 2 states: *Given EOQ WRSK items do affect aircraft readiness, is the magnitude of their effect dependent upon the treatment of cannibalization selected (full-cann versus no-cann)?* This required one last combined run employing a full-cann treatment for EOQ items.

When executed in the performance evaluation mode, Dyna-METRIC estimates performance measures for each day of the thirty-day scenario. Peter (14) has shown it is insufficient to evaluate the performance of WRSKs only at the end of the support period. Therefore, in the interest of looking at the range of the support period, without overly complicating presentation of the results, output was requested for days 1, 4, 7, 10, 15, 20, 25, and 30. It was felt that these increments would provide convenient graphical and tabular presentations from which to draw meaningful conclusions.

Table 3 presents the results of all four steps conducted in the experimental design, while Figure 2 addresses only research question 1. Research question 2 is graphically displayed in Figure 3. It was also felt that the behavior of the spares could be better tracked, analyzed, and compared if the results were dimensioned by days of conflict along the horizontal axis.

TABLE 3

EXPECTED NMCS AIRCRAFT

Day	1	4	7	10	15	20	25	30
Baseline								
EOQ (No-cann)				EXPECTED VALUE OF NMCS AIRCRAFT				
Combined (EOQ No-cann)				RESEARCH QUESTIONS 1 AND 2				
Combined (EOQ Full-cann)								

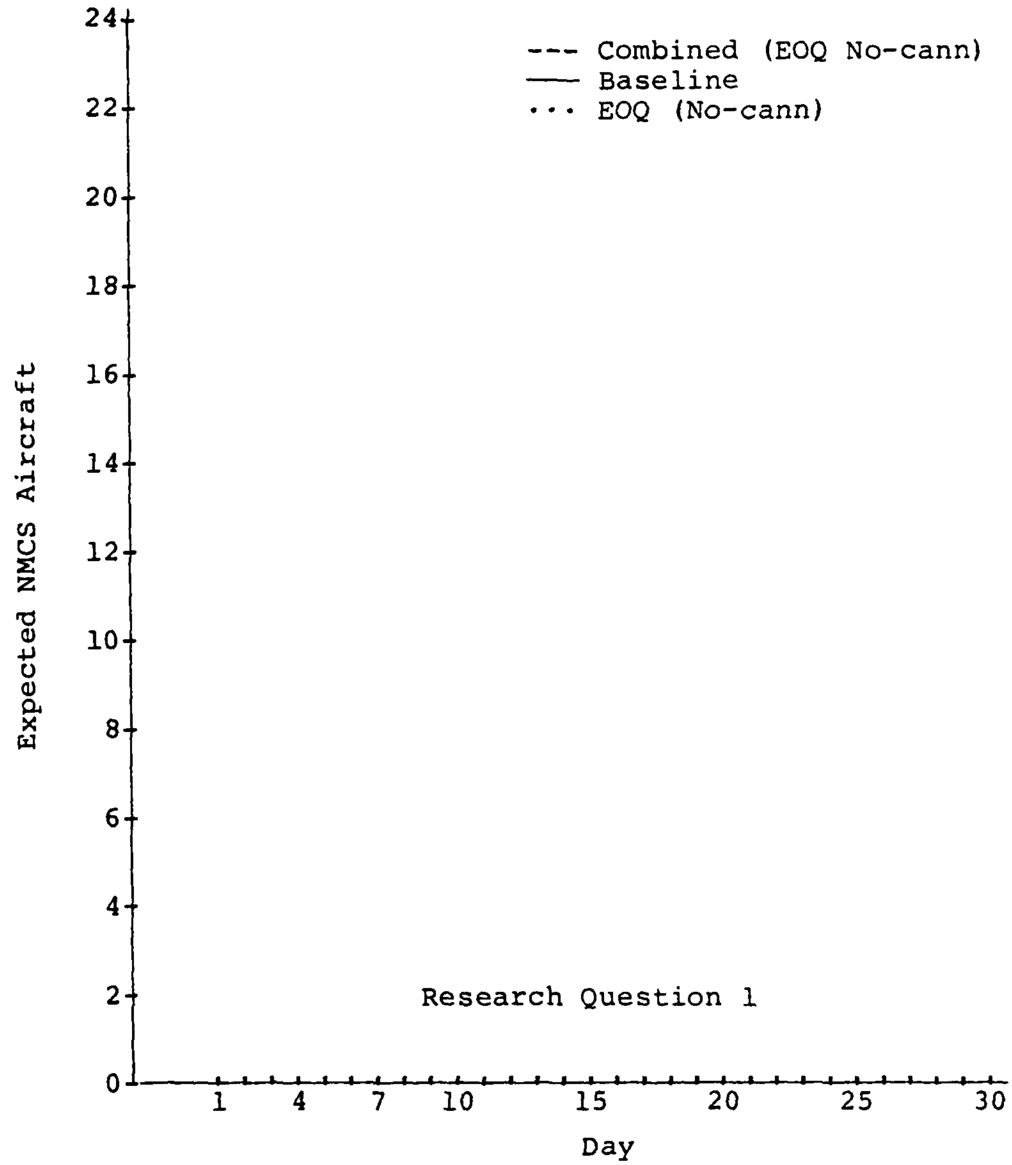


Fig. 2. The Impact of EOQ Items on Expected NMCS Aircraft

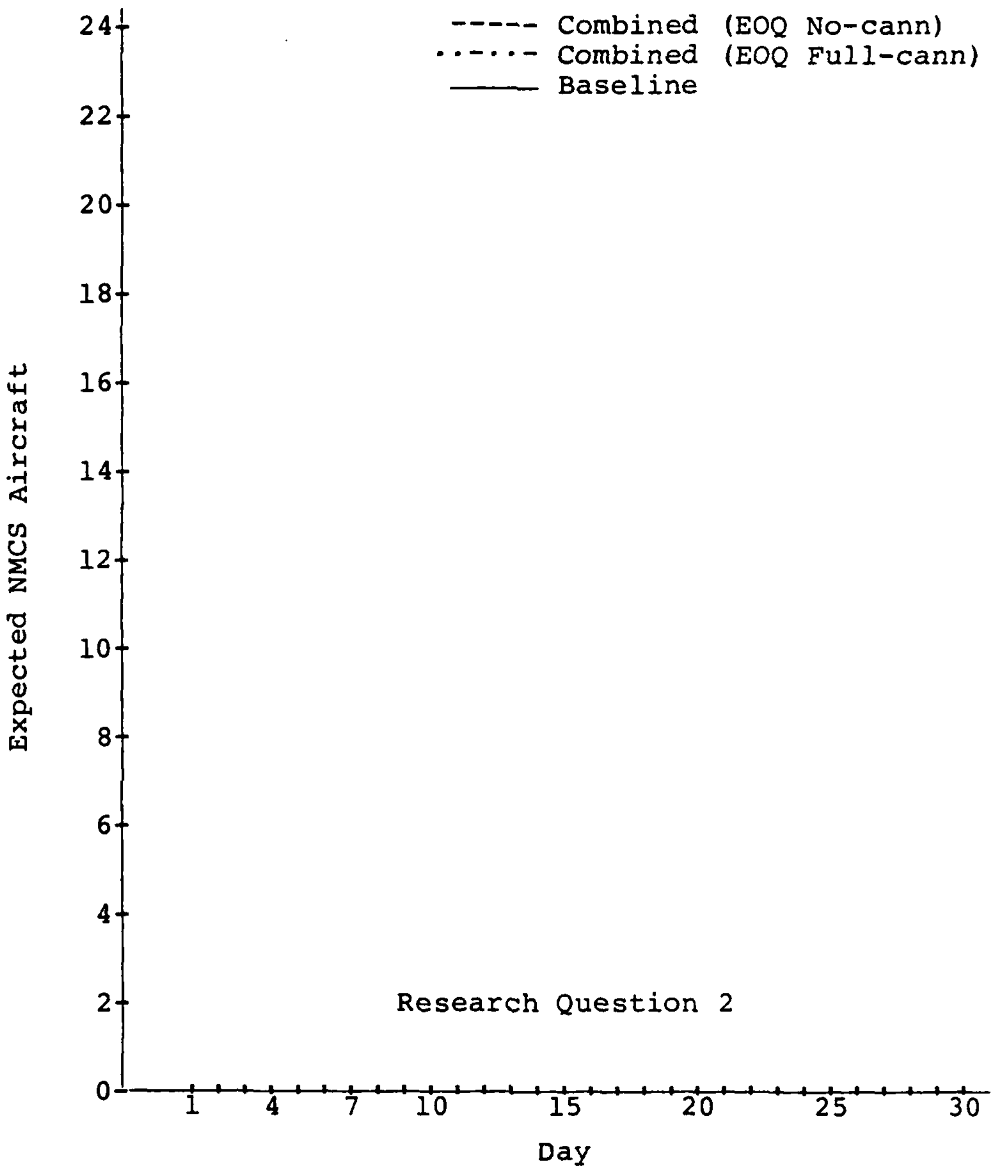


Fig. 3. Comparison of Cannibalization Treatment on EOQ Items

Methodology and Design Limitations

In addition to the Dyna-METRIC and D029 process assumptions previously discussed, there are certain assumptions associated with the methodology and experimental design that have not yet been examined. The discussion that follows will lay the necessary foundation upon which valid analysis and interpretation of the results will be possible.

First, because D040 authorized WRSK stock levels are used instead of actual stock levels, the results must be interpreted with the assumption that the kit is stocked at 100 percent. In the real world, this may or may not be true on any given day due to kit shortages. Also, recent additions/deletions to kit items are not reflected in the D040 selected records dated November 1982.

Second, certain assumptions regarding EOQ items must also be clear. Although a shortage of EOQ items could cause a PMC aircraft in the real world, Dyna-METRIC can only report the expected status of aircraft as either FMC or NMC. Furthermore, since only mission essential items are included in a WRSK, the EOQ items in the kit are assumed to be mission essential for FMC status. This assumption is the primary reason for discarding common hardware items (i.e., nuts, bolts, screws) from the data base. It is also due to this assumption of mission essentiality that EOQ items can be treated as LRUs in the Dyna-METRIC

model; as such, they can directly impact aircraft readiness. EOQ items are treated in Dyna-METRIC as single indenture items with 100 percent NRTS rate and infinite base, CIRF, and depot repair times. Additionally, demand per flying hour (where DDR is based on a unit of issue of "each") and QPA data must be known in order to treat EOQ items as LRUs. In addition, all next higher assemblies are assumed to possess a QPA of 1.

Lastly, the methodology further assumes that a linear relationship exists between the demand process and flying hours. For a variety of reasons, some EOQ items, as well as some recoverables, fail to exhibit a direct relationship between historical consumption data and the associated flying hour program. For these items, the process that generates the demands may be expenditure per sortie factor, or simply one of elapsed time. It would appear that EOQ items may possess a greater tendency for this to occur as compared to recoverables, but data needed for such a determination is currently unavailable.

The experimental design developed for this research has both strengths and weaknesses. One of the strengths is that all variable input parameters of the scenario are held constant. This enhances the ability of the researcher to isolate possible cause and effect relationships that may exist between recoverables, EOQ items, and the cost optimal stock levels required to sustain a specified level of

aircraft readiness. The matrix case study design also presents the results in an easily interpretable manner where trends should be readily recognizable.

Probably the greatest design weakness concerns the methodology used to determine cannibalization feasibility. Assuming that XB3 items are noncannibalizable because they are considered nonreparable is, at best, a reasonable estimate of their actual status. The other alternative, and preferred method, would have been to research the cannibalization feasibility of each item either through the applicable technical orders or by historical cannibalization actions identified by work unit codes in the Maintenance Data Collection System. Determination of cannibalization feasibility by almost any method is highly subjective or requires intimate knowledge of each item's specific function. Because the lack of objectivity and necessary detailed knowledge made any credible cannibalization classification scheme impractical, the authors settled for the XB3 breakout previously mentioned. Nevertheless, for the results of this research to be meaningful, it is necessary to assume that the screened XB3 data base used accurately reflects actual item characteristics regarding mission essentiality and cannibalization feasibility.

One final note, in order to minimize potential distortions discussed above, additional design features were incorporated which treat EOQ items as fully

cannibalizable. This should provide additional insight into both the behavior and impact of EOQ items as well as the impact that differing cannibalization treatments have on model outputs.

CHAPTER IV

RESULTS

Overview

The type and quantity of Dyna-METRIC output depends on the options specified, but it is generally quite extensive. Unless suppressed, Dyna-METRIC provides a detailed echo of all input data, including the scenario, flying hour program, and all information on each LRU and SRU. Based on the option selected for this research, output for each day consisted of: the probability of achieving the target NMC rate, the expected number of NMC aircraft for both the full-cann and partial-cann assumptions, the expected number of sorties flown, total backorders, and a listing of up to 150 problem parts and their associated probabilities of impact. The performance measure of concern in this research is the expected number of NMC aircraft for the appropriate cannibalization assumption. Since the meaningful information needed for analysis is such a small part of the output produced, rather than including extensive computer listings, the expected NMC aircraft will be summarized in tabular and graphical form as described in Chapter III. Additionally, the problem EOQ parts which have a significant impact on readiness will be identified.

Before the results are presented, however, the authors will discuss why the final EOQ data base was reduced from the size originally anticipated. Then, a final note concerning a recent update to Dyna-METRIC's version 4.2 will be offered. Following the presentation of the results, an interpretation and analysis, organized by research question, will be provided. A short summary will then lead to the conclusions and recommendations in Chapter V.

Determination of the Final Data Base

Upon receipt of the selected D040 containing 1865 EOQ items and the realization that QPA data could only be obtained for MMAC coded EOQ items, it was anticipated that there would be 304 noncannibalizable EOQ items to add to the baseline data base (recoverables only). However, when the QPA and demand data were received, and the EOQ items in the D040 were closely screened, additional EOQ items needed to be excluded from the final data base.

There were many reasons why parts were either intentionally excluded or could not be used in this research; a detailed breakdown follows. Because multiple data bases with different currency dates were used, some inconsistencies were found. Specifically, while the D040 contained 304 MMAC coded EOQ items, the QPA data from the ILDF did not contain 91 of these 304 items. This

discrepancy is primarily due to the recent emphasis placed on reducing the number of MMAC coded items (4). Nine items were excluded because the ILDF had incomplete information; specifically, it did not list next higher assemblies with their associated QPA. Thirty-three items had QPEI values greater than 99, and Dyna-METRIC currently only provides a two-digit field for this parameter. Seven items in the ILDF were listed strictly as alternate parts for a preferred primary part. QPA is not specified for alternate parts, but only for primary applications. One item was not listed on the T05 report; thus, usage data was not available. For the reasons just discussed, 141 of the original 304 MMAC coded items could not be included in the Dyna-METRIC analysis due to limitations of available data and/or the model.

The remaining 163 items were closely scrutinized to determine if any of the items should be intentionally excluded from the analysis. Of these remaining parts, twenty-four were common hardware items (e.g., nuts, bolts, cotter pins, light bulbs); thus, they were excluded because it was believed these types of items could and would be cannibalized, thereby lessening their potential impact on aircraft readiness. An additional seven items were excluded because it was believed they could also be cannibalized. Finally, nine items were discarded because their true mission essentiality was suspect. Therefore, forty

items were thrown out on the judgement that they either could be cannibalized or had questionable mission essentiality.

Although the resulting EOQ data base was about one-third of that originally anticipated, it nevertheless represented a workable and meaningful sample for conducting this research and satisfactorily answering the research questions proposed. In fact, subject to the assumptions previously identified, the final EOQ data base contains 123 mission essential, noncannibalizable EOQ items with accurate and current QPA values, demand data, and authorized stock quantities. If any EOQ items in this WRSK were to have an impact on aircraft readiness, it should be items from this group.

The Final Evaluation Model

Because the assumption of cannibalization is so critical to the research results, the authors decided to use a new cannibalization subroutine made available to HQ AFLC in August 1983. This subroutine is expected to be incorporated into the upcoming version 4.3 of Dyna-METRIC. This subroutine affords a more efficient and accurate treatment of cannibalization, especially regarding SRUs. The old subroutine tended to overestimate the expected number of NMCS aircraft in the no-cann mode. Although the change in NMCS aircraft due to the new subroutine was

small (since our data contained only seven SRUs), the Dyna-METRIC output using the no-cann treatment (see Table 4) reflect the impact of the new routine (approximately one less NMCS aircraft on days 4, 7, and 10). The reader is therefore reminded that the model used in this research was not the standard version 4.2.

TABLE 4

RESEARCH RESULTS: EXPECTED NMCS AIRCRAFT

Day	1	4	7	10	15	20	25	30
Baseline	.23	1.43	2.35	2.49	3.16	3.95	4.87	6.03
EOQ (No-cann)	.15	4.01	12.90	16.43	21.20	23.09	23.78	23.96
Combined (EOQ No-cann)	.35	4.07	12.90	16.43	21.20	23.09	23.78	23.96
Combined (EOQ Full-cann)	.34	1.69	3.05	3.73	5.86	8.72	12.37	16.49

Presentation of Research Results

Table 4 presents the expected number of NMCS aircraft from four separate Dyna-METRIC analyses designed to answer research questions 1 and 2. Figure 4 graphically depicts the effect of EOQ items on aircraft readiness by plotting expected NMCS aircraft against a scaled thirty-day axis. Figure 5 similarly displays research question 2, thereby showing the significance of the cannibalization treatment employed in Dyna-METRIC analysis.

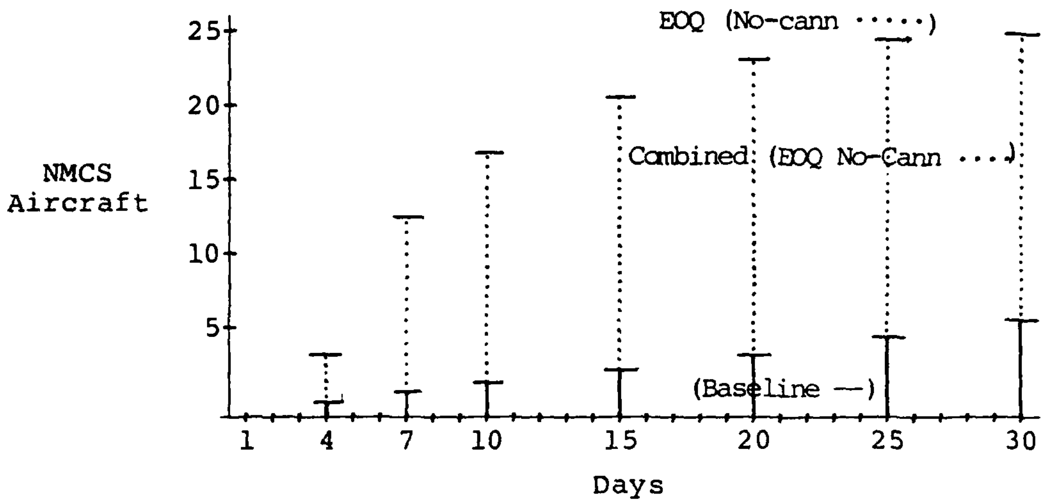


Fig. 4. Research Results: The Impact of EOQ Items on Aircraft Readiness

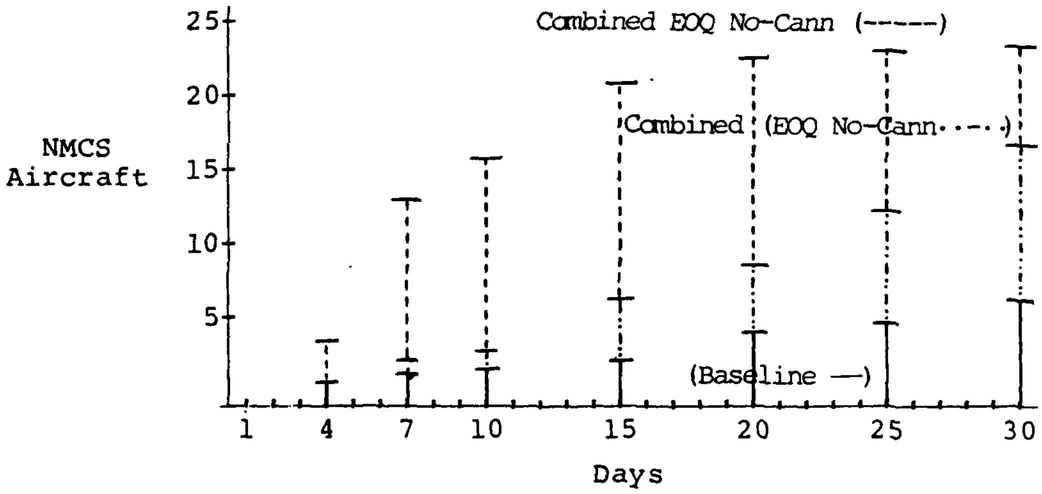


Fig. 5. Research Results: Output Sensitivity to Cannibalization Treatment

Analysis of Results

Research Question 1

The effect of EOQ items on aircraft readiness can be seen by comparing the baseline (row 1) with NMCS due to EOQ and recoverables combined (row 3) of Table 4, or by looking at EOQ items (row 2) singularly. Row 2, and the corresponding line in Figure 4, show the effect of EOQ items on aircraft readiness as if they were the only items in the WRSK. On day one there is minimal impact, while on day 4 there are 5 NMCS aircraft, with almost 13 on day 7. The surge of flying activity ends on day 7, and from this point on, the increase in NMCS aircraft gradually tapers off until day 30, where virtually all aircraft (23.96) are grounded due to EOQ items alone. For the EOQ items, this translates into a zero percent readiness rate. This is highly significant, given that EOQ items are stocked with the intention of providing a 100 percent readiness rate, and that a fifteen-day safety stock for each EOQ item is added to achieve this rate (18; 20).

The standard against which to compare the readiness support provided by EOQ items is the baseline run of recoverable items only in a full-cann mode (see row 1 of Table 4 and Figure 4). Once again, the impact on day 1 is minimal, and there is a relatively constant increase in NMCS aircraft of one-half to one aircraft per time increment specified within the thirty-day period. At the

end of day 30, there are 6.03 of twenty-four aircraft grounded, which is approximately equivalent to a 75 percent readiness rate (.7487), the level of support intended for recoverable WRSK items (18; 20).

Row 3 of Table 4, and the associated line in Figure 4, show the results of a Dyna-METRIC analysis of the recoverable and EOQ items in a single run, each with its respective cannibalization treatment. Without an item-by-item determination of cannibalization feasibility, this represents the most realistic situation possible. From day 4 on, the results of this combined run are almost identical to those of the EOQ items alone, which indicate that the shortages of EOQ items are driving the readiness rate of the whole WRSK. Indeed, parts with high demand rates and/or insufficient stock quantities will drive the readiness rate for a given WRSK. In comparing the combined run to the baseline, the EOQ items cause almost 2.52 additional NMCS aircraft by day 4, 7.91 by day 7, 3.39 by day 10, 4.1 by day 15, and then it quickly tapers off to zero additional aircraft on days 25 and 30. The end result on day 30 is that EOQ items grounded 23.96 aircraft whereas the recoverable items alone would have grounded only 6.03 aircraft. Thus, all aircraft in the squadron are grounded on day 30 of the conflict scenario. Note that the greatest increase in NMCS aircraft between time intervals occurs in

the first seven days where the greatest flying activity occurs (surge).

Given this tremendous increase in NMCS aircraft caused by inadequate stocks of EOQ items, it is important to determine how many and what type of parts caused this impact. An analysis of the problem LRUs listed by Dyna-METRIC showed that seven low cost EOQ items accounted for the majority of the additional NMCS aircraft. These parts are listed in Table 5. There were an additional seven EOQ items which were not stocked adequately, but which accounted for only a small portion of the NMCS aircraft. The WRSK Branch at HQ TAC reviewed the seven major problem EOQ items and confirmed that these parts were indeed true problem parts which were stocked inadequately. This action reduces the speculation associated with the assumptions of mission essentiality, cannibalization and QPA for these seven parts. This, in effect, suggests that the F-16 WRSK analyzed could reasonably be expected to ground the entire squadron of aircraft by day 30 due to insufficient quantities of fourteen problem EOQ items.

Additional Dyna-METRIC runs were made to estimate the quantities of the seven problem EOQ parts needed to provide the intended 100 percent readiness rate. These needed quantities are also listed in Table 5. As the results show, the level of stock required to maintain a 100 percent readiness rate varies according to the specific

TABLE 5

EOQ PROBLEM PARTS

NSN	Noun	QPA	Stock Level	Stock Needed	Dmd/ Flying Hour	Cost
4730010529423YP	Seal, Conical	20	20	100	.00143	$ 1.52
5315010594943YP	Pin, Straight, Headle	2	5	31	.00245	.53
5330010513558LE	Seal, Inboard Bearing	1	16	54	.01210	10.29
5330010513559LE	Seal, Outboard Bearing	1	16	38	.01592	16.16
5330010529832LE	Packing, Preformed	3	50	70	.03014	16.94
5330010535748WF	Packing, Preformed	3	5	13	.00143	.56
6665000221357AH	Detector Tube, Chemi	1	1	13	.00332	16.86

component analyzed. However, the total cost associated with stocking these seven problem parts is minimal. That is, for only an additional $1427.52, these seven problem parts could be stocked to levels which would not detract from the 100 percent readiness rate the WRSK should provide.

Research Question 2

As previously discussed in Chapter III, the assumption regarding cannibalization is the major potential weakness of this research. Therefore, it was essential to determine the sensitivity of Dyna-METRIC outputs to the cannibalization assumption used for the EOQ WRSK items. This question is answered by comparing the combined run with EOQ no-cann (row 3) and the combined run with EOQ full-cann (row 4) of Table 4, or looking at the appropriate portion in Figure 5. Row 3 of Table 4 was previously analyzed and showed a very sharp increase in NMCS aircraft (up to 12.90) during the surge period, with a gradual tapering off and 23.96 NMCS aircraft on day 30. When the EOQ items were specified as fully cannibalizable, the number of NMCS aircraft increased only gradually with each time interval specified, reaching a total of 16.49 NMCS aircraft at the end of day 30. The increase during the surge period was very small (2.05 aircraft) compared to that of the no-cann assumption (12.90 aircraft). The increase in NMCS aircraft occurs quickly in the surge period and tapers off

gradually for the no-cann assumption, while it begins a gradual increase in NMCS aircraft which continues throughout the thirty-day period. The pronounced difference between the two treatments is due to the fact that there is a much greater supply of spare parts (all grounded aircraft) in the full-cann treatment which is not available (only WRSK stocked quantities) in the no-cann treatment.

Because these two cannibalization treatments represent the two possible extremes, the true performance of the WRSK probably falls somewhere in between. Given the most optimistic treatment (full-cann), even though EOQ items have a smaller effect during the surge portion of the scenario, it ultimately grounds 16.49 aircraft by day 30. Even if the true WRSK performance lies closer to the full-cann values (Figure 5), the effect of the EOQ items on readiness is significant, although not as great as with the no-cann treatment (especially in the first half of the thirty-day period). Nevertheless, with the methodology developed, the authors felt confident that the true readiness figure actually lies closer to the no-cann values, and that the EOQ items have a major impact throughout the thirty-day scenario.

Summary

The original data base of EOQ items was expected to consist of 304 components. However, 141 of these 304

items could not be used due to data base inconsistencies, lack of necessary information, and model limitation. An additional 40 items were intentionally excluded because they could be cannibalized or had questionable mission essentiality. Thus, the final data base consisted of 123 noncannibalizable, mission essential EOQ items.

This data base contained the EOQ items most likely to affect aircraft readiness, and was of sufficient size to produce meaningful results. The results showed that EOQ items caused significant increases in NMCS aircraft throughout the thirty-day period. It was also found that the cannibalization treatment applied to the EOQ items caused significant variation in the results. Nevertheless, even with the optimistic full-cann treatment, EOQ items can greatly impact aircraft readiness.

AD-A134 447 AN ASSESSMENT OF THE IMPACT OF WRSK (WAR READINESS SPARES KIT) EOQ ITEMS O..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. 2/2

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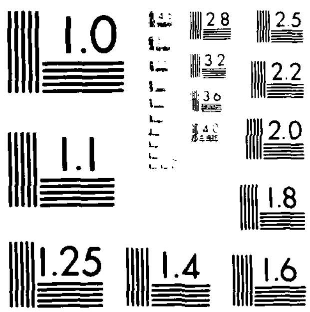

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Overview

This chapter will first review the key issues of this research effort in order to prepare the reader for a discussion of research conclusions. Following the conclusions, specific recommendations will focus attention on the actions needed to enhance WRSK capability assessments. Lastly, suggestions for further research will highlight areas of related research that are needed in this critical logistics area.

Summary of Research Effort

The anticipated operational capability of the Air Force is greatly dependent upon the availability of effective logistics support. WRSKs are designed to stock critical, mission essential parts to support thirty days of combat flying activity at a forward operating base until resupplied. The Air Force uses Dyna-METRIC to measure the readiness rate that can be expected from currently stocked recoverable items only. Until now, the potential impact that EOQ items have on aircraft readiness has been relatively undetermined by quantitative techniques. It is extremely important to understand the impact of these EOQ

items in order to assess the true support provided by WRSKs. Indeed, an aircraft can just as easily be grounded by a mission essential EOQ item as it can for a recoverable item.

This research developed a methodology to enable the Air Force to estimate the readiness provided by these EOQ items. The methodology consisted of treating mission essential EOQ items as single indenture LRUs with a 100 percent NRTS rate and infinite repair cycle time, and analyzing the items with Dyna-METRIC along with the recoverable items in the WRSK. The major effort of the research was to identify, obtain, and process the necessary data for Dyna-METRIC analysis. Specific information that the D040 lacked for this analysis was cannibalization, QPA, and demand per flying hour. A general assumption was made that nonreparable items (XB3) are noncannibalizable; the QPA data was obtained from the ILDF at Ogden ALC, Utah; and the demand data was obtained from Nellis AFB, Nevada. Additional supporting information (e.g., flying hours, scenario) were obtained from HQ TAC.

A single F-16 WRSK was analyzed which included 239 LRUs, 7 SRUs, and 123 EOQ items. The recoverable items received a full-cann treatment exclusively, while the EOQ items received a no-cann treatment, except for a single full-cann run to determine output sensitivity to cannibalization treatment. The results showed that several

inadequately stocked EOQ items significantly decreased aircraft readiness throughout the thirty-day scenario, as compared to the readiness provided by the recoverable items alone. It was also found that the results vary greatly depending upon the cannibalization treatment used. Constrained by previously identified research limitations, a discussion of the conclusions drawn from these results follows.

Conclusions

Research Question 1

The expected level of support provided by currently authorized WRSKs, measured in terms of aircraft availability, can be significantly reduced if adequate stock levels of the mission essential EOQ items in the WRSK are not accurately identified and maintained. With this research, a methodology now exists to estimate the impact of these EOQ items on aircraft readiness, although such an application has yet to be implemented. As the results show, a relatively small number of EOQ items were inadequately stocked, and these few items alone severely reduced the aircraft available for combat. Of course, the degree to which this conclusion represents a realistic assessment is contingent upon the methodology employed, the assumptions made, and the specific WRSK analyzed.

Because Dyna-METRIC analysis of EOQ items has been nonexistent and EOQ stockage procedures are subject to error, as evidenced by this research, one must conclude that the true level of support provided by WRSKs throughout the Air Force remains unclear. This will continue to be the case until all mission essential items in WRSKs (e.g., the entire WRSK, including EOQ items) are analyzed by Dyna-METRIC or a similar technique.

<u>Research Question 2</u>

As one might expect, the level of aircraft readiness is highly dependent upon the treatment of cannibalization employed when stock quantities are held constant. Throughout the thirty-day scenario, with the exception of the first few days, noncannibalizable EOQ items result in a significantly higher number of NMCS aircraft than provided by those same items assuming full cannibalization. One can only conclude that potential deficiencies exist in current stock levels for both recoverable and EOQ items alike. That is, for truly noncannibalizable components, the currently authorized stock quantities are likely to be inadequate, since they are based on and evaluated with a full-cann assumption, which tends to underestimate the actual amount of stock needed to meet a specific readiness rate. Although the full-cann assumption appears to be reasonable for a majority of recoverable items, those items

which are not cannibalizable are likely to result in less mission effectiveness than logisticians might expect. As discussed earlier, even using a full-cann treatment for the EOQ items, the results still show that 16.49 aircraft will be grounded at the end of the thirty-day period. When compared to the base line run with only 6.03 aircraft grounded, the potential impact of mission essential EOQ items remains significant.

Recommendations

Air Force logistics managers have been both creative and diligent in their development and use of sophisticated techniques for evaluating current and proposed inventory stockage policies. State-of-the-art inventory models, like RAND's Dyna-METRIC model, provide the necessary framework from which critical decisions directly impacting aircraft readiness can be made. However, current application, which includes only recoverable items, limits the depth and scope of these evaluations. As stated earlier, an airplane can just as easily be grounded for an EOQ component as it can for a recoverable item, yet Dyna-METRIC analysis of mission essential EOQ parts has not been accomplished.

Because it has been shown that EOQ stockage procedures are subject to error, it is imperative that an analysis similar to the methodology developed in this research be implemented to verify stock levels of WRSK EOQ

items throughout the Air Force. A recommendation for immediate action, however, requires that the stock quantities of the problem EOQ parts identified in this research be adjusted to correct the deficiencies noted. According to HQ TAC/LGSWW, the necessary stock level adjustments are currently being accomplished. This action will help restore the expected level of readiness provided by this specific WRSK.

WRSK managers also need to identify those mission essential components, both recoverable and EOQ, that for whatever reason, cannot be cannibalized. In terms of EOQ items, the maintenance technicians at base level who determine which items to include in a kit are probably best qualified to specify the cannibalization feasibility of each individual item. Then, the authorized stock quantities for noncannibalizable items should be adjusted upward to a point where these items would not have a significant detrimental impact on aircraft readiness.

Although primary focus should be placed on recoverables, at least limited inclusion of EOQ items into capability assessment evaluations should be undertaken. Only after mission essential EOQ parts have been identified (during annual WRSK/BLSS reviews) and then analyzed by Dyna-METRIC can we be fairly confident of the level of support that WRSKs reportedly provide. However, the data preparation/manipulation that was required in this thesis

is a tedious endeavor due to the availability/accessibility of needed EOQ input parameters. A cost/benefit analysis is needed to determine the feasibility of incorporating the needed information (i.e., demand per flying hour, QPA, and cannibalization feasibility) into the current D040 or other data base. Developing a single, integrated source of information on all mission essential components, regardless of ERRC code, for Dyna-METRIC analysis would greatly enhance the depth, scope, and utility of current aircraft capability assessments. Lastly, whether accomplished through existing data bases or the proposed integrated data base, items undergoing changes in demand experience due to the aging of a weapon system should be flagged for special attention and more frequent evaluation and update. In sum, the results of this study accentuate the need for increased attention on EOQ items contained in WRSKs and the cannibalization treatment used for both recoverable and EOQ items.

Suggestions for Further Research

This study dealt with a specific WRSK for the F-16 weapon system. A replication of this study is needed using different F-16 WRSKs before any broad generalizations can be made regarding the effectiveness of EOQ WRSK stockage procedures. Next, a comparable study using a different tactical weapon system (e.g., F-4, F-15, and A-10)

should promote a greater level of understanding of the Air Force logistics system and its relationship to aircraft readiness.

A better technique needs to be developed which will more accurately reflect the true mission essentiality, cannibalization feasibility, and demand per flying hour for individual EOQ components used for Dyna-METRIC analysis. This technique should greatly enhance the researcher's ability to select and analyze critical components, further augmenting the decision-making process in more practical terms. For example, the process which generates demands for a given EOQ item may be expenditure per sortie, rather than usage per flying hour. This requires special calculation of the demand rate similar to the many NOP items included in the D029 data base. Such action is necessary to insure that Dyna-METRIC output is both accurate and meaningful. The overall effect of using demand per flying hour when another demand-generating process is applicable needs to be determined.

At the same time, these same items may or may not be truly mission essential or cannibalizable. Further research is needed regarding the full-cann assumption generally employed for recoverable items. It would appear reasonable to assume that a certain portion, perhaps 5 to 10 percent, of recoverable items in many WRSKs simply cannot be cannibalized for any of the reasons identified in

Chapter II. These items need to be identified and treated as noncannibalizable in Dyna-METRIC analysis using 4.2 or later versions. Then, stock levels for these items can be increased to a level which will assure the stock quantities will support desired levels of aircraft readiness. Similar research to determine the effect of actual versus assumed mission essentiality of aircraft components should be conducted. It is clear that the more accurate and complete the input data used for analysis, the more and valid and credible the results should be.

A recent change to WMP-1, Annex E, dated April 1983 authorizes sixty days of stock (with no safety level) for EOQ items, rather than the previous thirty-day supply (plus a safety level). Therefore, future research using Dyna-METRIC is needed to verify the accuracy of these newly established stock levels. Also, the level of overall mission effectiveness provided by these levels should be examined, especially since organizational bench stock is no longer deployed with tasked units (20). In addition, an analysis of the impact that sixty days of authorized stock has on the strategic airlift that will be available during wartime may also be warranted.

A Final Note

It is extremely important for the reader to realize that readiness rates and expected NMCS values stated in

this research are in no way actual figures. Due to the probabilistic nature of Dyna-METRIC outputs, and the assumptions made regarding QPA, demand rates, cannibalization, and mission essentiality, these figures represent our best estimates of the expected readiness provided by the specific WRSK analyzed. Therefore, it is contingent upon senior Air Force managers to further refine the methodology developed in this research in order to promote greater levels of confidence in the estimates provided.

APPENDICES

APPENDIX A

ACRONYM DEFINITIONS

AFLC -- Air Force Logistics Command

ALC -- Air Logistics Center

BLSS -- Base Level Self-Sufficiency Spares

CIRF -- Central Integrated Repair Facility

D029 -- WRSK/BLSS Requirements Computation System

D040 -- WRM List/Requirements and Spares Support List

D041 -- Recoverable Item Consumption Requirements System

D062 -- EOQ Buy Computation System

DDR -- Daily Demand Rate

DRT -- Depot Repair Time

EOQ -- Economic Order Quantity

ERRC -- Expendability, Recoverability, Reparability Category

FMC -- Full Mission Capable

FSC -- Federal Stock Class

FSCM -- Federal Supply Code for Manufacturers

HQ -- Headquarters

ILDF -- Integrated Logistics Data File

LMI -- Logistics Management Institute

LRU -- Line Replaceable Unit

METRIC -- Multi-Echelon Technique for Recoverable Item Control

MMAC -- Materiel Management Aggregation Code

MTBD -- Mean Time Between Demand

NMC -- Not Mission Capable

NMCS	-- Not Mission Capable Supply
NOP	-- Nonoptimized
NRTS	-- Not Reparable This Station
NSN	-- National Stock Number
OR	-- Operational Rate
OST	-- Order and Ship Time
PBR	-- Percentage Base Repair
PMC	-- Partial Mission Capable
QPA	-- Quantity per Assembly
QPEI	-- Quantity per End Item
RCT	-- Repair Cycle Time
RET	-- Retrograde Time
RR	-- Remove and Replace
RRR	-- Remove, Repair, and Replace
SM	-- System Manager
SRU	-- Shop Replaceable Unit
TAC	-- Tactical Air Command
TFW	-- Tactical Fighter Wing
T05	-- WRSK Review Listing (TAC Report)
WMP	-- War Mobilization Plan
WRM	-- War Reserve Materiel
WRSK	-- War Readiness Spares Kit
XB3	-- ERRC Code designating nonreparable EOQ items
XF3	-- ERRC code designating reparable EOQ items

APPENDIX B

MMACS INCLUDED IN THE FINAL EOQ DATA BASE

Number of Items	MMAC	Item Management Grouping
1	AH	LGM-30 A, B, C (Minuteman)
1	AZ	Miscellaneous Aircraft Accessories and Systems
4	EW	Airborne Electronic Warfare Equipment
1	GG	Gunnery Equipment
10	LE	Aircraft Landing Gear Systems
2	TP	Temperature and Pressure Controls, Aircraft
85	WF	F-16
19	YP	Gas Turbine Jet Engines, Non-Aircraft
123 Total		

APPENDIX C

SAMPLE OF D029 DATA

Stock Number: 1005010566753

Item Type: NOP (alternates: LRU, SRU, EOQ)

Unit Cost: 30813.00

Maintenance Concept: RRR (alternate: RR)

Base Repair Cycle (Days): 7

Total Organizational Intermediate Maintenance
Demand Rate: 0.1552

Depot Demand Rate: .0062

Base Repair Rate: 0.1490

Quantity per Application: 1

Work Unit Code: 75AA0

Marginal Analysis Quantity: 2

Conventional Quantity: 2

Noun: Gun M61A1

Note Code: 2

Line Stock Due Outs: (blank for this item)

APPENDIX D

SAMPLE OF D040 DATA

Note Code: 2

Federal Stock Number: 6665000221357AH

Noun: Chemical Detector Tube

Manufacture Part Number: CH318

Unit of Issue: Box (alternates: roll, foot, hundred, etc.)

Unit Cost: $18.86

Procurement Source Code: F

Quantity: 1

Source of Supply: B14

Work Unit Code: (blank for this item)

Serial Number: 0F016A0T2400

ERRC Code: N

Budget Code: 9

Distribution Code: A

Extended Cost: $18.86

APPENDIX E

SAMPLE OF T05 REPORT DATA

Stock Number: 1095011003892

Nomenclature: Ejector 69J13060-5

Interchangeable/Prime Stock Number: 1095001664286

Date of First Demand: 2084

Cummulative Demand: 7

Independent Record Daily Demand Rate: .016

Weapon System Daily Demand Rate: (blank for this item)

Quantity Authorized: 4

Quantity Received: (blank for this item)

Mean Time Between Failure: 678.9

ERRC Code: XD2

APPENDIX F

SAMPLE COMPUTATION OF DEMAND PER FLYING HOUR

Demand per flying hour was computed for each EOQ item used in this research. The following data/values were used in the computations:

Total Hours Flown (180 days) = 10207.7

OPEI (computed from ILDF, see Appendix G)

Total Demands (computed from T05 Report)

<u>Example</u>

Part NSN: 105001443221WF

Weapon System DDR (over 180 days): .186

QPEI: 10

STEP 1: Total Demands = DDR x 180

$$= .186 \times 180 = 33.48$$

STEP 2: $\text{MTBD} = \dfrac{\text{Total Hours Flown x OPEI}}{\text{Total Demands}}$

$$= \frac{10207.7 \times 10}{33.48} = 3048.89$$

STEP 3: Demand per Flying Hour $= \dfrac{1}{\text{MTBD}}$

$$= \frac{1}{3048.89} = .00033$$

APPENDIX G

SAMPLE OF QPA DATA

Part National Stock Number: 12700105573

Part MMAC: WF

Part Number/Federal Supply Code for Manufacturers (FSCM):
11127-2 07148

Next Higher Assembly Part Number	FSCM	QPA
16E1343-801	81755	0001
16G1430-127	81755	0001
16G1430-61	81755	0001
16G1430-65	81755	0001
16G1430-87	81755	0001
	(computed) OPEI =	0005

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